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The Results of the T-45 Main Landing Gear Uplock Investigation and the Effect that Organization Structure Had on Them

Christina Marie Stack
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Christina Marie Stack entitled "The Results of the T-45 Main Landing Gear Uplock Investigation and the Effect that Organization Structure Had on Them." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

George W. Garrison, Major Professor

We have read this thesis and recommend its acceptance:

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Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Anne Mayhew

Vice Chancellor and Dean of
Graduate Studies

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THE RESULTS OF THE T-45 MAIN LANDING GEAR UPLOCK INVESTIGATION AND THE EFFECT THAT ORGANIZATION STRUCTURE HAD ON THEM

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Christina Marie Stack
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ABSTRACT

The T-45, a military jet trainer aircraft for the Navy, recently experienced two cases of an uncommanded main landing gear extension during high airspeed and high g conditions. These events resulted in an investigation to understand the cause. The initial response to the mishaps was to limit the fleet to lower airspeeds since both mishaps occurred at high speeds. This limitation was not extensively restrictive for fleet operations; however, it was limiting for acceptance flights and functional check flights of aircraft. During the investigations, two different mechanical problems were discovered in the main landing gear uplock mechanism. This mechanism is designed to physically hold the landing gear in the "up" position. The proposed fixes for the identified problems resulted in a new smaller diameter spring pin to remove mechanical interference between the wing structure and the spring pin. The second change was a new material bushing that was designed to remove the friction in the system and allow the latch that holds the uplock in place to move freely. During the investigation, it became evident that there was a lack of knowledge about the landing gear environment among the T-45 community. As a result of this lack of knowledge, the flight test group was asked to conduct a flight test and gather the data needed to ensure that the proposed fixes would completely solve the causal factors of the mishap.

The flight clearance for the proposed flight test required the incorporation of Naval Aviation Depot (NADEP) engineer's proposed corrections into the system. This mandate was met with confusion from the flight test community, due to the desire to investigate the initial configuration to determine the cause of the original mishap. The flight test

was performed with the corrections and no problems were identified, leaving a question as to the original casual factors. This course of events exemplifies a lack of communication between the flight clearance authority and the flight test community. An attempt was made to reverse some of the initial changes and return the uplock to the original state. It was finally determined that structural interference did create motion in the system, which could possibly result in the landing gear extension that had occurred. The flight test did not result in a full understanding of the original system; however, the test indicated that the new proposed system had no motion that would indicate that a future problem would exist. The new procedures and hardware were released to the fleet allowing the fleet to return to a full flight envelope.

This thesis investigates the problem of the uplock mechanism and the flight test that was designed and executed to assist in correcting these problems. It also investigates how organizational structure influenced this engineering investigation and affected the outcome of this test.

The flight test community, flight clearance community, maintenance engineering and program offices need to balance the risk inherent to flight test, and the level of understanding of the system under test against the potential knowledge gained by flight testing to determine a path of execution. There are times that flight test results may not enable engineers to understand the causal factors to a problem or define a correction to the problem. In this case, it is the author's opinion that there may have been information lost due to the process used to perform the test. However, the proposed fixes did solve the majority of the fleet's problems.

PREFACE

A portion of the information contained within this thesis was obtained during a Naval Air System Command sponsored program. The research, results and conclusions and recommendations presented are the opinion of the author and should not be constructed as an official position of the United States Department of Defense, the United States Navy, the Naval Air Systems Command or the T-45 program office.

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NOMENCLATURE

cm	centimeter
g	acceleration of gravity (9.8 m/sec^2 or 32.2 ft/sec^2)
lbs	pounds
in.	inch
mm	millimeter
psi	pounds per square inch
psf	pounds per square foot
Nx	Longitudinal Acceleration
Ny	Lateral Acceleration
Nz	Normal Acceleration

Acronym	
ACM	Aircraft Combat Maneuvering
AFB	Airframe Bulletin
AFC	Airframe Change
BuNo	Bureau Number
CR	Cruise
EI	Engineering Investigation
FCF	Functional Check Flight
GAM	Goshawk Advisory Memo
KCAS	Knots Calibrated Air Speed
KIAS	Knots Indicated Air Speed
MLG	Main Landing Gear
MSL	Mean Sea Level
NADEP	Naval Aviation Depot
NAS	Naval Air Station
NATOPS	Naval Air Training and Operating Procedures Standardizations
NAWCAD	Naval Air Weapons Center Aircraft Division
PA	Power Approach
RAMEC	Rapid Action Maintenance Engineering Changes
RFI	Ready For Installation
RTB	Return To Base
USN	United States Navy
VMC	Visual Meteorological Conditions
WOW	Weight-On-Wheels
WUT	Wind Up Turn

CHAPTER 1: INTRODUCTION

AIRCRAFT

The T-45C aircraft is a two-place, tandem, fully carrier capable, jet trainer for the USN. A detailed description of the test aircraft is available in the T-45C Naval Air Training and Operating Procedures Standardizations (NATOPS) flight manual, reference 1. There are two different models of the T-45, an A and a C model. The difference between the models is that the T-45C is equipped with an advanced avionics suite that is not installed in the T-45A. Students stationed at Kingsville, Texas fly the T-45A, while students stationed in Meridian, Mississippi are trained in the T-45C. There are no differences in the flying qualities or mechanical characteristics of the T-45 models. Tests that are discussed in this thesis were conducted on T-45C Bureau Number (BuNo) 163635 (A037), which is an instrumented aircraft stationed at Patuxent River, MD.

ORGANIZATION

The T-45 fleet is comprised of two training squadrons at Naval Air Station (NAS) Kingsville and NAS Meridian. To support those squadrons a program office is located at Naval Air Weapons Center Aircraft Division (NAWCAD), Patuxent River MD. The program office oversees and coordinates all of the support provided by the competency aligned organization of the Navy and the contractor / builder of the aircraft, Boeing St. Louis. All engineering support, for flight clearances and flight test support, from the Navy for the platform comes from the 4.0-engineering competency. Although competency aligned, the organization is not co-located. The organization to support the fleet operations is comprised of three primary groups: maintenance, flight test and flight clearance.

MAINTENANCE

For the maintenance engineering oversight, the Naval Air Depot (NADEP) is located at NAS Cecil Field near Jacksonville, FL. The engineers who support this facility are part of the 4.3 competency where the 3 is for the structures and airframe support group. When a new maintenance procedure needs to be verified, the engineers from this group in Florida need to travel to Meridian or Kingsville where the maintenance personnel are located and the maintenance is actually performed. Unlike most platforms in the Navy, the maintenance on the T-45 is completed by the contractor, not enlisted Navy personnel, and is completed at the site of the operational aircraft.

FLIGHT TEST

When a new system or piece of hardware is required, or a change to the standard operating procedures is required, flight test is completed by a team at Patuxent River, MD. This team is composed of engineers from the 4.11 competency where the 11 designates the flight test competency. For this uplock test, the engineers are part of the 4.11.5.1 competency where the 5 denotes the installed propulsion and mechanical systems branch and the 1 denotes the individuals as part of the fighter aircraft branch. The aircrew and aircraft used for these tests are aligned with the Strike Test Squadron, VX-23, (part of the 5.5 competency.)

FLIGHT CLEARANCE

When a new piece of hardware is designed for an aircraft, it must be cleared by flight clearance group, comprised of engineers from the 4.4 and / or 4.3 competency prior to installation on the aircraft with an approved flight clearance. This same flight clearance process applies to new maintenance procedures for the aircraft. The flight clearance defines the limitations to the flight test aircraft, or to the fleet, for the installation of the component or for the requirement to complete maintenance procedures after a certain number of flight hours. The 4.4 competency is responsible for propulsion or electrical changes to the aircraft. The 4.3 competency is responsible for structural, flying qualities and mechanical systems such as landing gear installed on the aircraft. Both of the 4.4 and 4.3 competencies are located at Patuxent River.

TEST PHILOSOPHY

In general, flight test teams are testing for improvements to problematic systems or issues on an aircraft. For preparation of the test, the team needs to understand the operational baseline in order to define the improvement. If nothing is known of the baseline, the team will attempt to gather baseline data for comparison. During preparation for this test, no data existed regarding the uplock mechanism and its environment as installed in the aircraft. Minimal subassembly testing on the uplock latch had been completed at the NADEP to investigate the forces required to move the uplock latch as installed on the test bench. In addition, a temperature survey was also completed to understand how temperature changes affected the forces measured in the uplock system. As stated above, the program office wanted to gain understanding of the uplock mechanism environment.

The test team wanted to gather initial data in the baseline configuration to understand the potential problems that existed in the system. However, the flight clearance authority decided that the original configuration was too risky and the team was required to make the NADEP suggested changes prior to testing. Test points were designed to put large loads on the landing gear and look at the vibratory characteristics of the landing gear system.

CHAPTER 2: BACKGROUND

THE AIRCRAFT PROBLEM

In 2001 there were two cases of a single leg uncommanded main landing gear extension during high airspeed and high g conditions. Both inadvertent extensions occurred during the high g recovery of the Functional Check Flights (FCF) dive profile above 0.9 M. The cases occurred on opposite sides; however, there were several electrical, hydraulic, mechanical, and aerodynamic similarities. Two Class "A" mishaps, as defined by the Naval Safety Center (Reference 2), caused by these gear failures occurred as a result of landing gear overspeeds. Mishap Engineering Investigations (EIs) identified a number of possible causal factors that may have contributed to the uncommanded landing gear extensions: inadequate Main Landing Gear (MLG) uplock over-center distance (Figure 1, Appendix A), interface dynamics between the uplock roller and latch (Figure 2, Appendix A), mechanical interference between spring pin components and the beam assembly (Figure 3, Appendix A), intermittent hydraulic pressure commanded by bad weight-on-wheels (WOW) proximity switches, and excessive uplock latch friction. A description of each of these failure scenarios is included below in the background section. What was not understood was if any single factor or a combination of factors was required for the failure condition to occur. Several fixes had been identified by the maintenance depot: a more robust WOW proximity switch, decreased friction in the main rotation point bushing, and reduced mechanical interference between the spring and aircraft structure. The T-45 MLG was held in the retracted position by a hydro-mechanical system, pressurized to 3000 psi by the hydraulic system 1 (HYD 1) and was electrically controlled. The locking system for the gear consisted of an uplock roller on the landing gear, an uplock latch mounted to the upper, internal structure of the wing, hydraulic actuators, and electrical WOW proximity switches. The interface dynamics between the roller and the latch, with the landing gear hydraulic system pressurized and depressurized, was still unknown. Landing gear hydraulic system response to an intermittent electrical signal from the WOW proximity switch and its effects on the landing gear selector valve was not well understood. It was theorized that a hydraulic spike would occur in the unlock line if the system became depressurized. The flight test team was tasked by PMA 273 to design a flight test program that would provide data to help understand the dynamic interface of the roller and the latch in damped (landing gear hydraulics pressurized, i.e. normal hydraulic system) and undamped (landing gear hydraulics depressurized) hydraulic conditions. In addition, the test program was to assist in determining the effect of intermittent WOW proximity switches on landing gear hydraulics and latch position.

EFFECTS ON THE FLEET

As a result of the single landing gear extensions occurring during high airspeed and high g dive recoveries, airspeed restrictions were placed on the fleet aircraft. This decision was made since high airspeed and high g combinations were common characteristics of the two inadvertent landing gear extensions. Limiting the airspeed also limited the g forces on the aircraft. Since students do not spend significant time at high airspeeds during their training period, the only portion of the curriculum that is affected is the ability to complete high speed aircraft combat maneuvering (ACM). This limitation also required the fleet to obtain a waiver, which would allow them to complete FCF profiles without the high-speed dive.

<u>MAIN LANDING GEAR DESCRIPTION</u>

To assist in the understanding of the casual factors, a description of the MLG system is included here.

MAIN LANDING GEAR

The T-45 MLG is held in the gear well by a hydro-mechanical system, pressurized to 3000 psi by the HYD 1 system and is electrically controlled. The locking system for the gear consists of an uplock roller on the landing gear (Figure 2, Appendix A), an uplock latch mounted to the upper internal structure of the wing (Figure 4, Appendix A), hydraulic actuators, and electrical WOW proximity switches (Figure 4-6, Appendix A). The latch is spring loaded to the locked position. With the latch in the fully closed, over-center position, the line of action created by the force of the roller resting on the latch imparts a closing moment to the latch, Figure 2, Appendix A. The production priority valve between the landing gear hydraulic lines and the remainder of the HYD 1 system ensured that problems within the landing gear system did not affect control of the aircraft. A schematic of the hydraulic system for the main and nose gear and for the electrical sequencing of the landing gear are found in Figures 7 and 8 (Appendix A) respectively.

MAIN LANDING GEAR DOOR

The T-45 MLG doors are attached to the aircraft by two hinges. The aft hinge can support a maximum load of 3892 lbs and the forward hinge 1587 lbs The door uplock mechanism, one in each wheel bay, consists of a roller on the door and an uplock bracket mounted on the aft face of the auxiliary spar, Figure 5 (Appendix A). The latch over-center and spring enable the uplock mechanism to mechanically support a maximum load of 5130 lbs A Boeing structural analysis on the MLG door, (appendix B) indicated that with the wheel resting on the door at 1g, the resultant loads on the aft hinge, forward hinge, and uplock bracket would be 78.7 lbs, 36.2 lbs, and 106.1 lbs respectively. The forward hinge, the limiting component, could sustain the force of the gear on the door up to 23.2 gs (appendix B).

POSSIBLE CAUSAL FACTORS

OVER-CENTER DISTANCE

In the uplock mechanism, Figure 1 (Appendix A), the over-center distance was defined as the calculated perpendicular distance between the load line and center of the hook pivot point. The load line was defined as the line from the contact point of the hook/roller, which passes through the roller center. Over-center distance was designed to be a nominal positive 3.50 mm. Accounting for production tolerances of the uplock mechanism components and wing deflections during flight, this over-center distance could be as small as 0.45 mm. When combined with the mechanical interference, there was a concern that the over-center distance would become small enough to allow the roller to push the latch open and allow the gear to fall onto the gear door during wing deflection conditions. A Boeing engineering finite element model was used to predict wing deflections. A tolerance survey of the uplock components, which included allowances for the interference due to wing deflection, determined that each mishap aircraft had a positive 0.85mm over-center distance.

UPLOCK ROLLER AND LATCH DYNAMICS DURING AIRCRAFT MANEUVERING

Longitudinal movement of the roller within the clevis and latch hook may reduce over-center distance, Figures 1 through 2 (Appendix A). In the up and locked position, the roller is held in place between the uplock clevis and uplock latch. The theory was that the roller might float between the clevis and the latch with increasing positive g. Roller float combined with the dynamic response of the roller and latch, and a small over-center distance, may produce a negative over-center distance that will allow the roller to fall past the latch into the gear well under positive g loads greater than 2.3 g. Once the gear has fallen past the dagger lever that sequences the changeover valve, the gear door will be hydraulically commanded open. Under sufficient g, the outward force on the gear would overcome the retract actuator and allow the gear to fall into the airstream.

MECHANICAL INTERFERENCE

Mechanical interference between the uplock assembly upper spring pin and the wing beam assembly cutout was identified as another significant factor in uncommanded gear extension. As the g force on the aircraft increases, the wing structure deflects causing the wall of the spring pin structural slot (see Figures 2 and 3, Appendix A) to push the spring pin upward. This interference causes the uplock latch to rotate in the unlocking direction while the roller simultaneously overcomes the actuator force and rests on the latch. Design and assembly tolerances allow for this condition. In this situation, significant interference could allow the latch to fully open and allow the gear to extend under high g conditions when the weight of the gear overpowers the retract actuator resulting in the gear extending at high g and high-speed conditions.

FRICTION

High uplock latch friction forces could impede return of the uplock latch to the fully closed position following the mechanical interference noted above. The maximum allowable frictional force for the installed uplock latch was designed to be 9 lbs with the gear extended and 6 lbs with the gear retracted as defined by Boeing, reference 4. In-lab tests indicated frictional forces decrease as the temperature decreases. However, when similar temperature comparison tests were conducted at high levels of humidity, the frictional forces increased significantly as the temperature decreased. The landing gear actuator was designed to hold the gear in the up position against the top of the uplock clevis. However, further analysis revealed that above 2.3 gs, the actuator is no longer able to support the weight of the gear. At this point, the uplock latch was responsible for retaining the roller while the hydraulic pressure provided damping of gear roller motion. If spring pin interference under high-g loads moves the latch, and friction prevents the latch from closing, the roller could fall out of the uplock mechanism. If the gear passed through the dagger lever, the gear door would be commanded open. Above 2.3 gs the gear would continue to overpower the retract actuator and extend into the airstream which would result in aircraft damage at high speeds.

WEIGHT ON WHEELS PROXIMITY SWITCH FAILURE

The aircraft was designed with a WOW proximity switch to prevent the gear from being retracted on the ground. Age or maintenance malpractice were believed to have caused cracks in the ceramic switch faces which allowed moisture intrusion on both of the mishap aircraft. Bench testing, at Jacksonville and St. Louis, indicated sporadic open and closed WOW proximity switch failures. Ground testing also indicated that moisture at the crack locations could cause the state of the switch to oscillate between open and closed. If this switch failed in the open position (weight-on-wheels), the landing gear selector valve would be de-energized and moved to the neutral position (hydraulic power removed from the landing gear system). While in the neutral position, hydraulic pressure in the landing gear system is not available to hold the roller against the uplock clevis or provide damping against undesirable motion. If the switch failed intermittently the landing gear selector valve would toggle between the neutral and locked position. Therefore, if power was removed, the roller rested upon the uplock latch and relied solely on the latch to hold the roller and landing gear in position. Under these conditions, the movement of the roller between the clevis and latch was described as undamped. The belief was that flight maneuvering and buffet conditions in an undamped state combined with a small over-center distance would increase the probability of an uncommanded gear extension.

The theory was if the WOW proximity switch intermittently fails to weight-on-wheels, the landing gear selector valve de-energizes, the "lock" line depressurizes, and a pressure spike occurs in the "unlock" pressure line. If this spike was large enough, that hydraulic pressure could drive the uplock latch to the open position via the gear uplock actuator, Figure 6, Appendix A. With the latch in the open position, the following sequence is assumed to occur:

a. The roller releases and the wheel assembly rests inside of the gear door (gear door would remain closed due to the lack of hydraulic pressure therefore the gear does not inadvertently extend into the airstream).

b. The WOW proximity switch then re-energizes to weight-off-wheels, which commands the following simultaneously:

1. The landing gear selector valve repressurizes, which commanded the gear actuator to re-raise and re-lock the gear.

2. The gear door opens momentarily due to the return of the hydraulic pressure.

c. After the gear moved up past the dagger lever and returned to the position between the clevis and latch, the gear door closed and locked.

INSTRUMENTATION

The three instrumentation modifications made to the airframe included: a video camera aimed at the uplock mechanism in each MLG well, accelerometers in the left MLG well, and a switch in the cockpit to simulate failed WOW proximity switch.

HYDRAULIC LINES

In order to document pressure in the lock and unlock lines of the MLG hydraulic system, both of the hydraulic lines on the left uplock actuator were instrumented with wet pressure transducers. The transducers limited the use of the aircraft due to the potential loss of hydraulic pressure in the event of a transducer failure; therefore, the instrumented lines were installed only during hydraulic pressure spike investigation flight.

CAMERA SYSTEM

A 30-frame/second camera and light source were mounted in each MLG wheel well in order to monitor the roller and latch motion, Figure 9, Appendix A. The video was monitored real time to ensure that the gear was up and locked.

COCKPIT CONTROL SWITCH FOR CONTROL OF LANDING GEAR SELECTOR VALVE VOLTAGE

The hydraulic pressure in the landing gear system is controlled by voltage signals from the WOW switch to the selector valve. When 28V is supplied to the selector valve (weight off wheels), the hydraulic system is pressurized to 3000 psi allowing normal retractions or extensions. When voltage is removed from the landing gear selector valve, removing hydraulic pressure from the MLG system, the landing gear roller goes to the neutral position and rests upon the main landing gear uplock latch. Instrumentation wiring was tapped into pin-A of the MLG selector valve in order to bypass the WOW proximity switch and allow control of the 28V via a control switch in the cockpit. A schematic of the installation is seen in Figure 10 (Appendix A.) The switch in the forward cockpit was placed on the right console as seen in Figure 11 (Appendix A.) The switch was labeled with "NORMAL" and "DISABLE" positions. In order to move the switch between positions, the switch had to first be pulled upward and then moved to the appropriate position, which ensured that the switch was not accidentally moved during flight. Placing the cockpit switch in the "DISABLE" position created the simulated failed WOW proximity switch since no voltage was going to the selector valve thus removing the hydraulic pressure in the uplock system. Leaving the switch in the "DISABLE" position allowed the roller and latch interaction to be investigated in an undamped condition. Toggling the switch represented an intermittent WOW proximity switch and was used to investigate a potential hydraulic pressure spike in the lock and unlock lines of the uplock mechanism.

ACCELEROMETER BLOCKS

Three accelerometers, in X, Y, and Z axes, were mounted on the left wheel well, upper internal surface of the wing, Figure 12 (Appendix A.) Three accelerometers, in X, Y, and Z axes, were mounted on the left MLG, approximately six inches up the strut from the uplock roller, Figure 13 (Appendix A). All accelerometers were Endevco model 7290A-30.

CHAPTER 3: TEST EXECUTION AND RESULTS

SCOPE OF TESTS

The evaluation was conducted during a one-hour ground test and six dedicated flights of approximately one hour each during daylight visual meteorological conditions (VMC) within the local restricted areas of NAWCAD Patuxent River. Turbulence and temperatures were not recorded during the flight test portion of this test. Ambient temperature measurements of the uplock mechanisms were approximated during the maintenance investigation. The test envelope is presented in Table 1. The test configurations are defined in Table 2. A full documentation of the test results can be found in the interim and final test report, references 5 and 6 respectively.

Table 1
T-45C TEST ENVELOPE

Parameter	Actual maximum value achieved	Test Limit/ Original NATOPS Limit	Aircraft Limit(1)
Airspeed	468 KIAS	550 KIAS	480 KIAS
Altitude	33,630 ft MSL	41,000 ft MSL	41,000 ft MSL
Mach number	0.94	1.04	0.8
Angle of Attack	MAX Available	None	None
Load Factor	7.8(2)	7.33g sym > 5K(3)	7.33g sym > 5K(3)
Gear Airspeed	N/A	200 KIAS	200 KIAS
Gear Load	N/A	0-2 g	0-2 g

Note: (1) Current NATOPS Restriction as a result of uncommanded extensions, prior to the completion of the Rapid Action Maintenance Engineering Changes (RAMECs).
(2) Measured for less than a second during to Wind Up Turn (WUT) due to pitch buck.
(3) Calculated based on aircraft weight.

Table 2
T-45C TEST CONFIGURATIONS

Configuration	Flaps	Slats	Gear	Speedbrake	Comments
Cruise (CR)	Up	Retracted	Up	Retracted	
Power Approach (PA)	Full	Extended	Down	Extended	
Ground Test	N/A	N/A	As Required	N/A	Aircraft on Jacks External Power External Hydraulics

METHOD OF TEST

The test matrix for ground and flight test conducted is presented in table 4 (Appendix C). Flight test consisted of Wind Up Turns (WUTs), high-speed dives, and pushovers to collect information on roller, latch, and landing gear. In addition to the flight maneuvers, hydraulic pressure in the landing gear system was manipulated through the use of the cockpit control switch. Ground latch force test data was collected with the use of a digital camera, hand held force gauge and a ruler. During the flight tests, onboard video, altitude, airspeed, aircraft Nx, Ny, and Nz of the wing and landing gear accelerometer blocks were monitored. Flight test points were built up from high to low altitude and low to high g. As a safety method, all test points were completed with the landing gear hydraulics depressurized, to prevent the landing gear door from opening in the event that the landing gear roller fell past the latch leaving the landing gear resting on the door. If the hydraulics had not been depressurized, the roller falling past the latch would have resulted in another inadvertent landing gear extension. For the simulated failed WOW proximity switch test, pressure transducers were installed in the unlock and lock pressure lines of the left main landing gear uplock mechanism. The pressure measurements enabled the test team to confirm if the landing gear selector valve was working per design.

RESULTS AND EVALUATION

GROUND TESTS

Installation of Components

Rapid Action Maintenance Engineering Changes (RAMECS) 021 and 023 procedures were verified and completed at NAS Kingsville and published as Airframe Change (AFC) 266 and 267, respectively. The verification set of uplocks were then shipped to NAWCAD Patuxent River as Ready For Installation (RFI) components for test purposes. Prior to removal of the non-reworked uplocks, force measurements of the uplock latch were taken as required by Airframe Bulletin (AFB) 180, and were less than 7.5 lbs on either uplock. The AFC uplocks were then installed into A037 (SD205).

After installation of the uplocks, with AFC 266 and AFC 267 incorporated, the friction measurements were taken with the gear down. The left uplock measured 7.5 lbs and the right uplock measured 10 lbs. The uplock springs were removed and the spring forces were individually measured. The springs were outside their 6 lbs limit by between 0.25 lbs and 1 lb and the four springs were replaced. The final limit in AFC267 rev A was 6-7 lb, which would have allowed the original test springs to be acceptable under the new procedures. The individual uplock mechanisms were also visually inspected, and the right uplock appeared to be sticking when manually attempting to rotate the latch. The RFI uplocks were then disassembled and the shim material was measured. The right uplock had three shims totaling 0.012 in. which did not provide the appropriate amount of required freeplay (0.002 in.), so the shims were replaced with two shims that were 0.014 in. thick and created 0.002 in. of freeplay. With the new shims, the right uplock was able to rotate freely under its own weight; however, when reinstalled the uplock still measured over 9 lb gear down. When the measurements were repeated by different people or in a slightly different location or direction on the latch, different values were obtained by up to a 1 lb force difference between measurements. Engineering logs of the maintenance completed and the measurements taken during the troubleshooting time are included in Appendix D. This 1 lb is greater than the 10% variation in measurement compared to the maximum allowed 7.5 to 9 lbs force measurement. The technique for measuring uplock mechanism friction, described in AFC 267 did not produce repeatable values. For this reason, post maintenance installation friction measurements in AFC 267 were removed via AFC 267 Amendment 1 (AFC 267-1). AFC 267 was not an acceptable procedure as released due to the invalid measurement techniques. The recommended procedures for measuring the individual spring forces and verifying that the installed uplock latch rotates freely under its own weight with the springs disconnected were accepted as a replacement for AFC267 and AFC 267–1 in AFC267 Revision A.

While troubleshooting the AFC 267 and 267-1 uplocks, the right uplock appeared to have a friction band in the target link assembly bushing, Figure 14 (Appendix A.) This bushing was original equipment and not changed or redesigned by AFC267 or AFC267-1. The friction was reduced when the target link assemblies were disassembled and cleaned, the bushing inspected, and the system put back together enabling the components to meet the free-fall requirements. The target link assemblies were found to be a contributory factor to the overall friction in the uplock mechanism. AFC 267 and AFC 267 Amendment 1 were not acceptable as written because they did not address the additional friction in the uplock mechanism due to the target link assembly bushing. The target link bushing procedures were added to AFC267 Revision A. It was recommended to add a time interval inspection of the system to ensure that excessive friction is discovered and promptly corrected, however, this recommendation has not been accepted by the NADEP at this time. Since the target link assembly bushings were cleaned and replaced, and the free fall requirements were met, the uplocks for the rest of the test will be referred to as AFC 267 with representative revision A incorporated for the remainder of this document.

Over-Center Distance

Since over-center distance was considered one of the largest contributing factors to gear inadvertently falling, the team decided to try to calculate the over-center distance of the two test uplocks. Using the cameras that were installed for real time flight monitoring and a ruler, the team attempted to get the measurements required to calculate the installed over-center distance as shown in Figure 1 (Appendix A.) The aircraft was placed on jacks, the gear was raised and the gear doors were left open. Several techniques were attempted to collect the needed information to calculate the over-center distance. The first was to hold rulers in the wheel well and use the installed video system, lights and cameras. The large amount of light that was provided by the installed video systems created a glare that washed out the ruler measurements and the uplock components. The video system light was then disconnected and a small external light source was used to prevent the wash out of the ruler measurements and components. This technique created human interference, since the space where the rulers have to be placed is very confined. Marks were then placed on the airframe structure, which was slightly in front of the uplock mechanism, and the external light source was used to take the still pictures using installed video system. The pictures came out very clear, without a large amount of distortion or human interference. The pictures were printed and analyzed; however, since the components were not well labeled and the cameras were not placed at a 90° angle to the uplock mechanism, a parallax was created which prevented accurate over-center measurements. Due to the difficulties associated with obtaining the over-center measurement, the requirement was dropped. An over-center measurement was not possible within the scope of this test. To avoid the parallax discovered during this test, I recommended removing the wheel assembly and using of a camera placed at a 90° for over-center measurements or other measurements of this type in the future. I also recommend making well-defined marks and measurement markings on the system in the same plane as the mechanism for future measurements.

FLIGHT TEST

Airspeed restrictions were originally placed on the fleet aircraft as an attempt to prevent any further events of landing gear inadvertently extending in flight. This decision was made since a common characteristic of the two inadvertent landing gear accidents was a high airspeed and high g combination. By limiting the airspeed the intent was to limit the available g of the aircraft as well. The possible causal factors listed earlier, identified

Table 3
UPLOCK CONFIGURATIONS FOR FLIGHT

Configuration	L Uplock	R Uplock
A	AFC 266 and 267 with representative revision A	AFC 266 and 267 with representative revision A
B	AFC 266 and 267 with representative revision A	AFC 267 with representative revision A

items other than airspeed that were to be investigated during this test, mainly component installation, buffet and g characteristics. In order to minimize the potential of inadvertent landing gear extensions, flights 1606 through 1610 were flown with reconfigured uplock mechanisms that had incorporated AFC 266 and AFC 267 with representative revision A incorporated. The next flight, 1611, was the hydraulic pressure spike investigation. No noticeable motion was observed during initial testing. AFC 266 was then removed, reinstalling the larger spring pin into the right-hand uplock assembly, in attempt to initiate latch motion during flight. The final flight, 1620, was with the larger spring pin and was comprised of WUTs with the hydraulics depressurized. A table of uplock configurations is documented in table 3.

Wind Up Turns

Wind Up Turns (WUTs), where g is maintained by sacrificing altitude in a turn, were used to create buffet and g conditions to understand the roller and latch dynamics. Test conditions were created based on the wing buffet response contour plot depicted in Figure 15 (Appendix A.) Proposed WUT test points were determined by looking at the buffet contour plot and increasing in g and decreasing in altitude within the envelop of the mishap aircraft as depicted in Figure 16 (Appendix A.) Initial WUTs were performed with the hydraulics depressurized (undamped latch/ roller contact) to ensure that the gear door would not open if the roller fell past the latch during the maneuvers (Appendix B). The remainder of the WUTs were completed with normal hydraulic pressure (damped latch/roller contact). A final set of test points was completed with the hydraulics depressurized (undamped) with the thicker diameter spring pin installed in the right side of the aircraft. On the first attempt to complete the 7g WUT with the pitch buck phenomena and the placement of the instrumentation, the aircraft achieved 7.8g for less than a second, which exceeded the 7.33 g limit. In order to prevent any future g exceedences, the remainder of the 7 g WUTs were completed with a 6.5g target. A plot of the WUTs that were completed in the undamped and damped configurations is presented in Figures 19 and 20 (Appendix A), respectively.

Wind Up Turns With AFC 266 and 267 With Representative Revision A Completed (Configuration A)

WUTs with AFC 266 and 267 with representative revision A completed, configuration A, were used to evaluate the roller and latch dynamics that might be occurring in the landing gear environment. Prior to conducting tests points depicted in Figure 16 (Appendix A), a pushover to 0.5 g at 10,000 ft was performed to understand the response of the free-floating roller. Turns were started at high altitudes, low Mach number and low g with a buildup in g and then in Mach number. All of the undamped dynamics points were completed prior to the damped dynamics WUTs. During the evaluation the cameras were used to evaluate any potential motion that was occurring during the test point. During the undamped dynamics points, the only motion detected occurred when the cockpit switch was moved to the DISABLE position, at which point the roller would fall on the latch. This movement of the roller falling on the latch is loud enough to be heard in the cockpit. During the damped points, the only motion detected occurred on test points that were over 3 g, when the roller fell away from the top of the clevis. A potential for the roller to fall past the latch did not occur at any time during any of the wind up turns. In configuration A, no roller or latch dynamics were discovered that would cause the inadvertent landing gear extension. Since the uplock mechanism showed no tendencies to move during WUTs with both AFCs installed, no conclusion could be drawn as to the cause of the inadvertent gear extensions which resulted in two class “A” mishaps. With the AFC 266 and 267 revision A installed the uplock system operated satisfactorily and should prevent future inadvertent landing gear extensions.

<u>Wind Up Turns With AFC 266 Removed From Right Uplock (Configuration B)</u>

After no motion was detected during the WUTs and FCF dive profile test points with configuration A installed, it was necessary to investigate if potential motion existed in the original configuration. The only configuration that was deemed safe enough to investigate was with the larger diameter spring pin installed (pre AFC 266) in one of the uplocks. The airplane was then reconfigured to configuration B, and as a preventative measure, test points 2-1 through 2-20, of Table 4 (Appendix C), were completed. For safety reasons the first flight was flown in the undamped state to prevent the landing gear door from opening in the event that the roller fell past the latch. During the first several points at 5g and below no noticeable motion occurred. On test point 2-17 of Table 4 (Appendix C), at 15,000 ft MSL, 6.2g and 0.79 M no noticeable motion occurred. At the next test point, 11,000 ft, 6.5g and 0.72 M, slight motion on the spring was noticed in the direction to open the latch. The g levels achieved on the 6.5g point in all three axes on the wing and the landing gear accelerometers are depicted in Figure 17 and 18 (Appendix A), respectively. Even with the motion of the spring no motion of the latch appeared. On a subsequent test point targeting a higher Mach number point, only 6.2 g was achieved. No motion of the latch or the spring was observed. No further points were repeated as a safety precaution. Without AFC 266 installed, slight motion is evident in the spring in the direction of opening the latch. When combined with a small over-center distance this could pose as a potential cause for the inadvertent landing gear extensions.

Function Check Flight Dive Profiles

The two events where the landing gear inadvertently extended during high g and high airspeed conditions are presented in Figure 16 (Appendix A). The first event occurred at PAX during the recovery from an FCF dive. The second event occurred at NAS Kingsville during a high speed dive recovery. In order to look at the landing gear environment during high g and high airspeed conditions, FCF dives were performed in the undamped and damped conditions in configuration A. As a build-up, the undamped profile was completed first. Two dives were performed after the completion of all other testing at the end of flight 1610. The undamped and damped dive profiles are depicted in Figures 19 and 20 (Appendix A), respectfully to demonstrate where the test points were in comparison to the dive profiles of the mishap aircraft and the originally planned test points. The maximum recovery pulls of the undamped and damped dive profiles were 3.35g at 473 KIAS on the undamped and 3.7g at 473 KIAS, respectively. No motion was observed in either uplock. High speed and high g created during the dive profile created no evidence for a potential cause for the gear to inadvertently extend with AFC 266 and 267 with representative revision A incorporated. With the AFC 266 and 267 revision A installed, the uplock system operates satisfactorily and should prevent future inadvertent landing gear extensions. AFC 266 and 267 revision A are now incorporated into fleet aircraft.

Hydraulic Pressure Spike Test

To analyze the concern of potential hydraulic fluctuations that would occur in the event of intermittent proximity switch failure, the hydraulic spike test flight was completed. During this test AFC 266 and 267 with representative revision A were installed. Two wet pressure transducers were installed on the left uplock lock and unlock actuator lines to measure the hydraulic pressure in each line. The pressure transducers were sampled at a rate of 430 Hz to capture any hydraulic spikes. The control switch that was installed at the beginning of the program that allowed for the undamped and damped WUT investigation was now used to toggle and created fluctuating pressures in the lock and unlock lines of the uplock mechanism. The hydraulic spike test was completed on flight 1611. The flight was limited to airspeeds below 180 KCAS (20 KCAS below NATOPS gear transition/ extension limit) as a risk mitigation for the potential hydraulic spike in the unlock line and possible inadvertent landing gear extension which were under investigation. The test started with monitoring the hydraulic pressure during a normal landing gear extension. The gear was retracted and the switch was then used to turn off the hydraulic pressure for different periods of time and toggled at different frequencies to simulate a failed intermittent WOW switch. During the test, no tendency for the roller to fall past the latch was observed. A video clip of test point 4-2, from flight 1611 is included as Figure 21 (Appendix A). When the gear is in the up and locked position, the lock pressure is maintained at approximately 3000 psi, Figure 22 (Appendix A). When the switch was toggled, the largest pressure that was observed in the unlock actuator lines was less than 450 psi, Figure 23 (Appendix A), during test point 4-6 of Table 4 (Appendix C.) The lack of large pressures in the unlock line indicates that the pressure is inadequate to physically open the latch. During normal operation, approximately 2900 psi is provided to the actuator to open the latch, Figure 24 (Appendix A). The hydraulic pressure spike that occurs in the unlock line during a simulated intermittent WOW proximity switch is significantly smaller than pressure that occurs to open the latch for a normal gear extension. With AFC 266 and 267 revision A an intermittent WOW switch was not considered a contributing factor for inadvertent landing gear extensions.

CHAPTER 4: ORGANIZATIONAL EFFECTS ON TEST RESULTS

BACKGROUND OF ORGANIZATIONAL STRUCTURE AND PROBLEMS

There were several issues that occurred during the planning and preparation of the project that were due to the unusual group dynamics. According to Fred Luthans, reference 7, the factors that can decrease group cohesiveness are the following: disagreement on goals, large group size, unpleasant experiences, intragroup competition, and domination by one or more members. Although the group had a common goal to safely get the fleet a full NATOPS envelope, it is my opinion that for this test all of the issues defined by Luthans existed for one reason or another among the contractor, the maintenance support, the flight test team, and the flight clearance team, which made achieving this goal a difficult task.

CONTRACTOR

The contractor initially disagreed about the need for this test and was unwilling to support the requirement for the test. The contractor believed that the problem had been identified and was going to be fixed with the mechanical changes recommended by the maintenance engineers. Although these changes were going to be a positive improvement, based on ground testing and the mishap investigation, it was not certain that other contributory factors were not present: i.e. high vibrations, or the potential of hydraulic spikes. After discussions with the contractor, it appeared that the major concern was that the flight test results might result in a possible redesign. If the design was found to be inadequate, the contractor would face a significant financial obligation.

The risk was a disincentive to perform the test, even though it was admitted that the landing gear environment was not well understood.

MAINTENANCE SUPPORT

Maintenance support personnel from Navy system engineers in Florida, and contract maintainers in Texas were involved in troubleshooting the problem that was limiting the fleet flight envelope. The engineers in Florida were part of the civil service support of the Navy, the maintainers in Texas were Boeing contractors. In addition to the maintainers in Texas there was a group of Boeing maintainers at Patuxent River, on a different contract, whose sole function is to support the two flight test aircraft at Patuxent River. In general, the maintenance team was comprised of a set of groups whose conflict arose from protecting their own interest, decreasing their group cohesiveness to support the maintenance actions required to correct the uplock problem.

The initial engineering investigations of the mishap aircraft proved that there were a few mechanical changes that could be made to improve the system reliability. While these hardware improvements were in the paperwork cycle for release to the fleet for execution, the test team was planning a flight test program that would determine if there were other causal factors related to the mishaps. The flight test investigation would allow the team to determine if the proposed improvements were actually improvements. The goal was that the flight test would be completed prior to releasing the procedures to the fleet, giving the program confidence that the procedures were adequate.

FLIGHT CLEARANCE

In the overall organization, the flight clearance team is considered the system experts and has the authority to impose and remove limitations on flight conditions of configurations of a fleet and/or flight test aircraft. According to Luthans, reference 7, authority legitimizes and is a source of power, which could be observed in the role that the flight clearance team held in the execution of this test. The role as the system expert enabled the flight clearance group to impose restrictions that were not considered reasonable by the flight test team in order to determine the true cause of the initial mishaps. The limitation imposed required the flight test aircraft to fly in the NADEP approved fleet configuration with the improvements already in place. The imposed limitation was a result of the unpleasant experience caused by the two mishaps that had already occurred and the fear that any limitation or lack of limitation would be a reflection of the flight clearance organization if the flight test resulted in another mishap. The use of power at the time reduced the opportunity for group cohesiveness since the imposed flight clearance severely restricted the flight test team's ability to determine a causal factor.

FLIGHT TEST TEAM

The flight test team had to deal with several obstacles on the road to meet the ultimate goal, safely getting the fleet a full NATOPS envelope. The flight test team has the responsibility to find the source of problems. The perception regarding this responsibility can be positive or negative, depending on where an individual resides in the organization. The program office would like to understand if there are any unknowns out there and would also like to prove that the proposed solutions are solutions. The contractor would not like an answer that costs money, but would like to know that the problem is fixed. The maintenance team would like to ensure that their proposed fix works, however, would not like a failure. The flight test either answers the problem or is the start of a new investigation, if the problem still remains. The flight test team also has no authority to change the flight configuration if the tests need to be performed outside the current fleet limit or if the configuration is not approved for the fleet. Although there is a lack of authority there is the perception that the flight test engineers do have what is considered Expert Power (Luthans, reference 7, page 361.) The flight test group's expert power is based on their extended experience with the aircraft as well as fleet experience. The flight test group's expert power provides some leverage when trying to obtain new limits.

The desire of a flight test engineer is to modify a configuration as little as possible, while maintaining safety, and then modify one item at a time in order to obtain clear test results. It is difficult to understand the cause when more than one variable has changed at the same time. Therefore, the test team tried to maintain the original configuration with a plan to modify one component at a time. This plan included the necessary safety precautions that needed to be in place. The team struggled to use the knowledge gained about the safety precautions that were in place combined with and the concern that the test would not produce the desired results if executed in the changed configuration, demonstrating again the lack of group cohesiveness. Unfortunately, the test team's recommendation did not prevail due to the overriding fear.

TEST IMPACTS

TEST PLANNING

The flight clearance for the test aircraft mandated that the proposed test could not be performed with the current installed configuration uplocks for safety reasons. The flight test team struggled with this requirement, since it was believed that the initial problem would not be understood if the mandated changes did fix the problem. The concern that another mishap could occur during the testing became the overriding factor and the restriction for the new components remained. With this restriction, the purpose of the test changed from gaining understanding of the initial cause of the mishap, to ensuring that with the flight clearance mandated fixes installed there were no lingering problems. The flight test team believed that the installed cameras provided a level of safety not present before. The test team would be able to observe dangerous trends during the build-up from low speeds with low g components to those with higher airspeeds and higher g components. The lack of fundamental understanding of the landing gear system environment created significant discomfort for the flight clearance team who is ultimately responsible for the limitations placed on the fleet. Although several arguments to fly the mishap configuration were made and the safety precautions were explained, the flight clearance mandated uplocks were installed for the start of testing. .

EFFECTS ON GROUND TEST

Providing an RFI set of uplocks in time for the flight test team to start testing, prior to release of those procedures to the fleet, was a difficult problem for the maintenance team in Texas. In order to modify a set of uplock components for flight, it was necessary to complete a validation and verification of the procedures. Early in the preparation the flight test team and all members of the maintenance support team decided that the validation and verification should not be performed on the flight test aircraft. Procedures were validated at the maintenance facility in Texas and RFI uplocks were delivered to the flight test team.

As stated earlier, the RFI uplocks did not properly install into the test aircraft. The friction levels exceeded the maintenance procedure requirements. Initially, the theory was that the friction measurements were being taken with an inappropriate technique. Several measurement attempts with different techniques and different individuals taking the measurements were made to try and understand the problem. After several days of unsuccessful troubleshooting, there appeared to be a condition that Luthans describes as Functional Conflict (reference 7, page 316) between the NADEP and the flight test team, since the flight test engineers were rewriting maintenance procedures based on troubleshooting completed on the flight test aircraft. This functional conflict occurred when the flight test team claimed that there was something wrong with the uplocks maintenance procedures as installed on the flight test aircraft. Flight test engineers are accustomed to finding problems with a product, but generally allow the contractor or NADEP to find a solution. The engineer maintenance support felt that the flight test engineers were overstepping the bounds of their responsibilities. It was determined that the only method to resolve the conflict and resolve the installation problem was to allow the NADEP engineers from Florida to aid in troubleshooting the procedures. Once the engineers were on site, the troubleshooting was completed fairly quickly and new procedures were released. With the new procedures released and the uplocks cleared for flight, the test was finally able to begin.

EFFECTS ON FLIGHT TEST

As stated earlier, the requirement to perform flight test with reconfigured uplocks installed was imposed due to the perception of high safety risk using older uplocks. The flight test team hoped that there would be no additional problems discovered, however this created a dilemma for the test team. With no other problems identified, there was no way the team could confirm that a problem existed with the old uplocks as configured in the mishap aircraft. Early in the planning stages, the question was posed to the flight clearance group what would be the troubleshooting path if no problems were identified with the new uplocks installed. The flight clearance team felt that the old uplocks presented an unacceptably high risk, however that a flight test was needed to confirm the new uplock's viability.

At the completion of the WUT phase of testing, there had been no obvious problems identified. At all of the high g points there was no obvious movement of the system. The team then investigated the hydraulic pressure. The hope was that the pressure changes, as seen in Figure 23 (Appendix A), might lead to the ultimate causal factor. Unfortunately, the results were inconclusive and the team was left without an obvious answer. The flight test team, using the experience and results of the tests that had been completed, requested a new flight clearance that would allow the original configuration to be flown. The flight test community felt that it was their responsibility to find an answer, even if the answer was that there was no problem with the initial installation. At the end of the evaluation with the flight clearance mandated uplocks installed, everyone on the team was left without an answer. Opinions were now changing as to the need for further testing with some part of the original uplock. It was in everyone's best interest to prove that the new maintenance procedures had fixed the problem.

The flight test community led the discussion with the flight clearance authority about options for future testing and the lack of an answer from the previous testing. Using the results of no motion of any component of the uplock during previous testing, and the increased knowledge that if the hydraulics were depressurized, that the landing gear could not fall into the airstream and result in third mishap, the flight test team was able to gain the clearance to test with the larger spring pin installed. The system engineers believed that the larger spring pin was the most likely cause for motion in the system and thus prove that a problem had been resolved with the new hardware. After the first series of testing with the old, larger diameter, spring pin installed, motion was observed during the WUTs. The T-45 program office concluded that the problem had been resolved and future mishaps resulting in the possible loss of aircrew and aircraft was eliminated.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

TEST RESULTS

Through several iterations of testing, it was determined that the large spring pin diameter and the friction in the uplock mechanism were the contributory factors of the two mishaps. The hydraulic pressure spikes that were believed to occur, did occur, however, they were not large enough to open the latch. The intermittent proximity switches are possible contributors when combined with a high amount of friction in the system; however, the proximity switches alone could not have contributed to the mishaps, due to the small magnitude hydraulic pressure spikes in the system. Although the lock line drops approximately 2500 psi during the switch toggling as seen in Figures 22 (Appendix A), the unlock line experiences only an average 250 psi spike increase during the same toggling as seen in Figure 23 (Appendix A.) This 250 psi is minute compared to the 2700 psi that is required in the unlock line during a normal gear extension, Figure 24 (Appendix A.) The requirement for the new component was released to the fleet, and at the current time, all fleet aircraft have the new components installed and have returned to a full fleet NATOPS operational limits.

TEAM INTERACTION

Team interaction was a driving factor in the outcome of this uplock test. A mechanical system that has been installed and operational for several years would seem simple to test and prove. In a time when job security is in question in the aerospace market, even in a government job, the maintenance support team had a conflicting goal in the design of the maintenance solution for the uplock problem. The goal to ensure that they maintained their jobs ensured that they participated in the design solution. At the same time, the government and contractor were competing with each other to avoid being perceived as the responsible party in the decision. Despite the shared goal of saving the fleet from future mishaps, the decision making of both maintenance teams also considered the issue of whether the system improvement was going to justify the cost for fleet implementation. Lower level independent goals and barriers can prevent the attainment of the ultimate goal. The lower level goal included avoiding incurring additional costs, while the fear of not having complete understanding of the system and the lack of knowledge of previous problems created a barrier to getting to the ultimate answer or what was the initial problem. Ultimately, the team was able to overcome these barriers to determine that there was a problem and with the testing completed, eliminated problem with the current installation.

RECOMMENDATIONS

TEST RESULTS

From the results of the ground test and the flight test, the recommendation to install the new components was confirmed. However, there are still two outstanding recommendations that will probably not be implemented for political and financial reasons. The first recommendation was an interval inspection on the components to ensure that dirt did not induce friction into the uplock components that would increase the risk of the uplock failure. The reason for not accepting this recommendation is that the inspection was invasive to the landing gear system and that it would require a large amount of down time on the aircraft, because the disengagement of the springs would cause several follow on ground tests that were time consuming. Also, the system experts believed that the problem would be identified during preventative maintenance inspections of the landing gear and that separate inspections were not required.

The second recommendation was a redesign of the system. Although, the system that is currently installed is acceptable for the task, it does not allow adequate margin for error in friction, installation or spring stiffness. There still remains a possibility that a future inadvertent landing gear extension could occur for an unknown reason. The design of the test described here is very limited in scope. There are other areas, including the proximity switches that are in the redesign process that should decrease the possibility of a failure. However, with a gap in the latch, there remains the remote possibility that the roller can fall past the latch into the airstream. Since the re-design requirements would be very extensive and costly, it was determined that the redesign would not be pursued. The primary fleet operational envelope is inside the envelope that was imposed to prevent the failure. The redesign recommendation would be a stronger one from the test team if the exposure of the fleet to high g and high airspeed test points were more frequent.

TEAM INTERACTIONS

It is important when everyone has the same goal that the team takes the time to concentrate on the goal. If necessary, as it was in this test, bring the team members together, especially when not centrally located, and work to find common norms and standards and a path to achieve the ultimate goal. It is also important for the team interactions, to build trust and knowledge that authority will not be misused. Teams need to understand each other's strengths and weaknesses. When teams are not co-located, this understanding is not gained easily, causing internal struggles as demonstrated in this team. Team interaction can make or break the outcome of a test. It is important to make sure that a positive interaction is occurring early in the planning stages.

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2. http://www.safetycenter.navy.mil/aviation/aeromedical/downloads/PocketReference.pdf

3. A1-T45AB-130-000 WP 32 30, Technical Manual for T-45 Landing Gear of 1 Aug 1997, Change 4-1 Nov 1997.

4. Boeing Goshawk Advisory Memo (GAM)-308 "Inspection of the Main Landing Gear Uplock Assembly, Approved 21 June 2001.

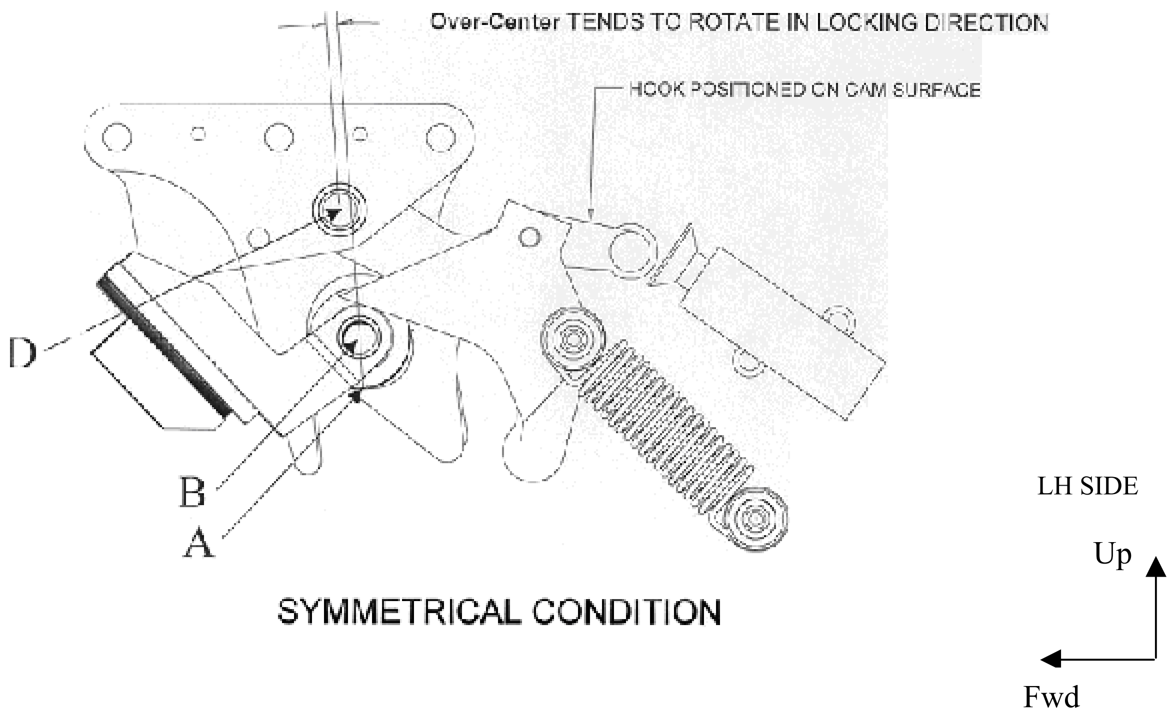
5. 201930Z JUN 02, NAWCADPAX-MSG-2002-121, T-45 MAIN LANDING GEAR UPLOCK.

6. Stack, Christina M.; T-45 Main Landing Gear Uplock Investigation (NAWCADPAX/RTR-2003/4) December 2003.

7. Luthans, Fred, *Organizational Behavior, Eighth Edition*, McGraw-Hill, New York, 1998.

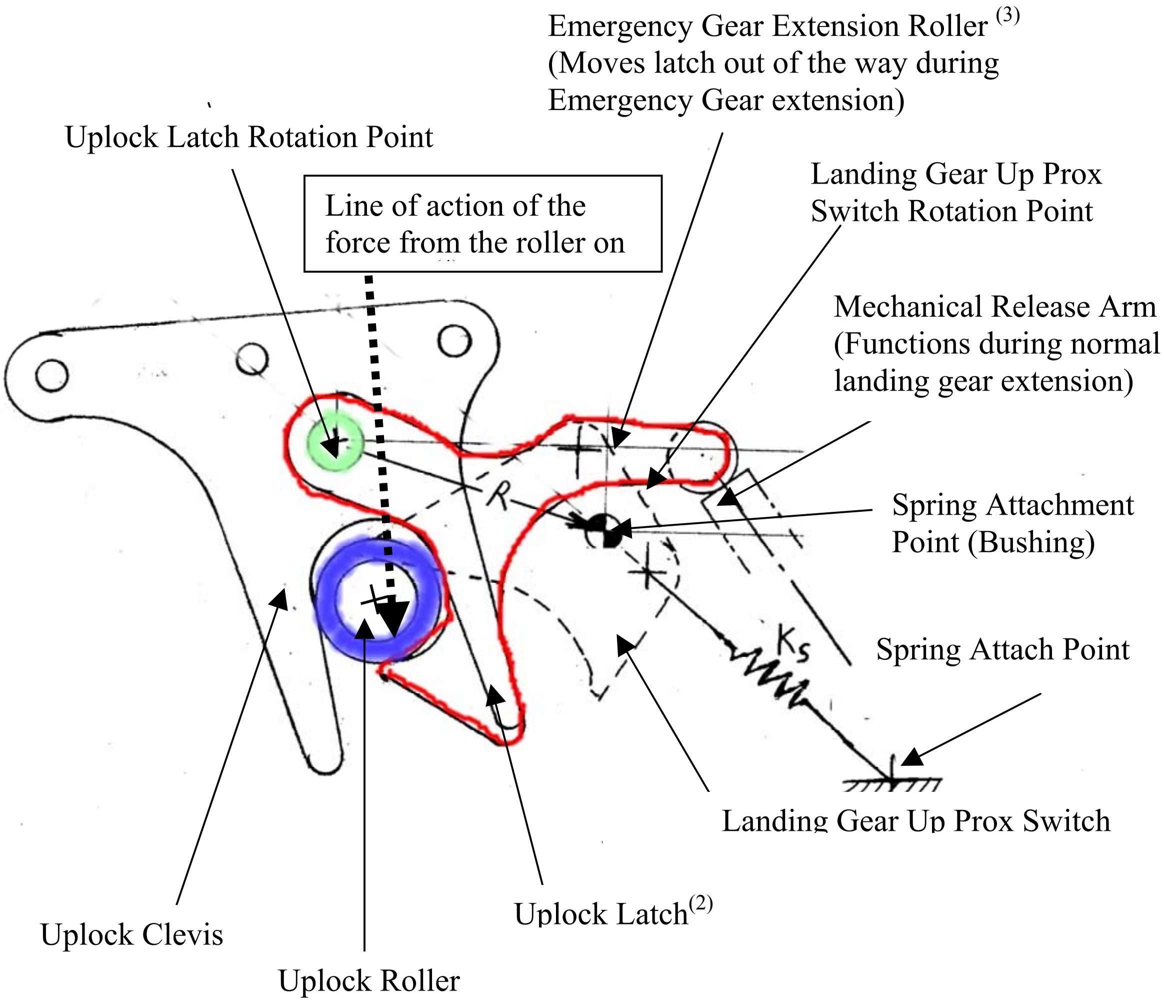
APPENDICES

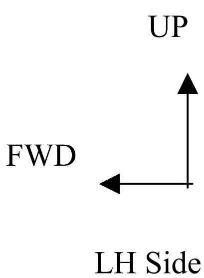
APPENDIX A:
FIGURES



MLG stowed, load line is measured as the line formed from connecting the contact point of the roller on the hook (A) through the center of the roller (B). Over-center dimension is calculated by taking that load line and measuring the distance from the center of the hook latch pivot point (D).

Figure 1: MAIN LANDING GEAR UPLOCK OVER-CENTER DISTANCE





Notes:

(1) This drawing shows the latch as it would be mounted to the aircraft with the roller up, but resting on the latch and the landing gear in the locked position.
(2) The uplock latch is always in the locked position
(3) The emergency landing gear extension manual release arm is omitted from this drawing.
(4) As the contact point of the latch and the roller moves it will shift the line of action relative to the rotation point of the latch. This will create either a locking or unlocking moment.

Figure 2: MAIN LANDING GEAR UPLOCK MECHANISM
(UNINSTALLED FROM AIRCRAFT)

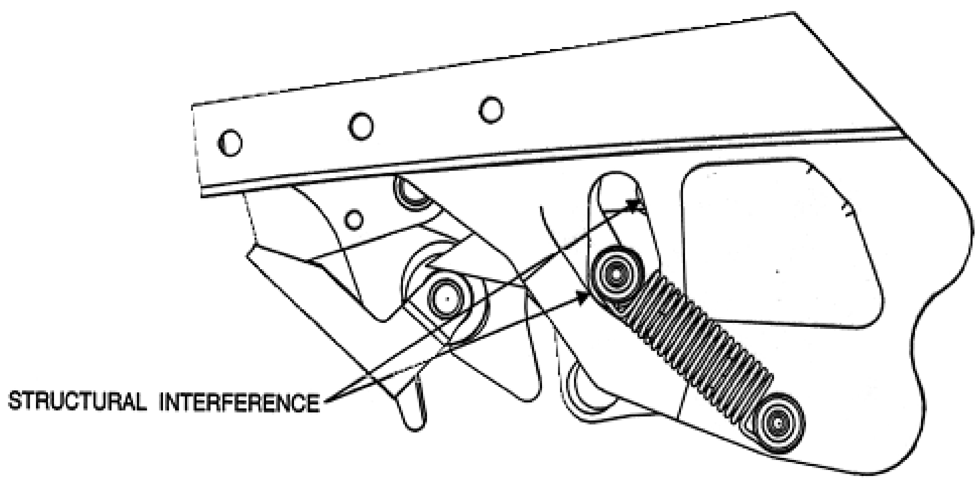


Figure 3: MAIN LANDING GEAR UPLOCK LATCH MECHANICAL INTERFERENCE
(GEAR UP AND LOCKED)

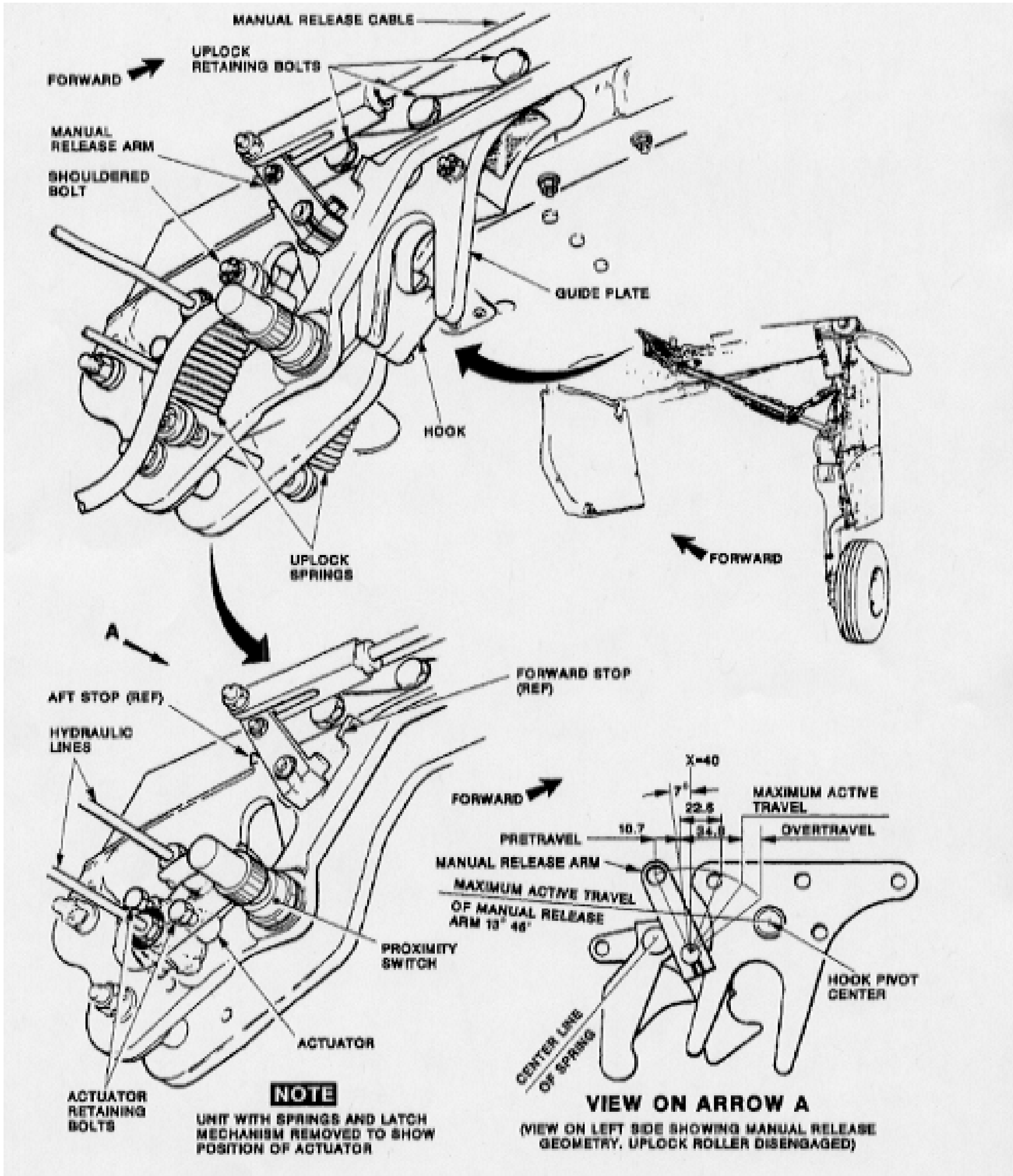


Figure 4: MAIN LANDING GEAR UPLOCK
(Technical Manual, Reference 3)

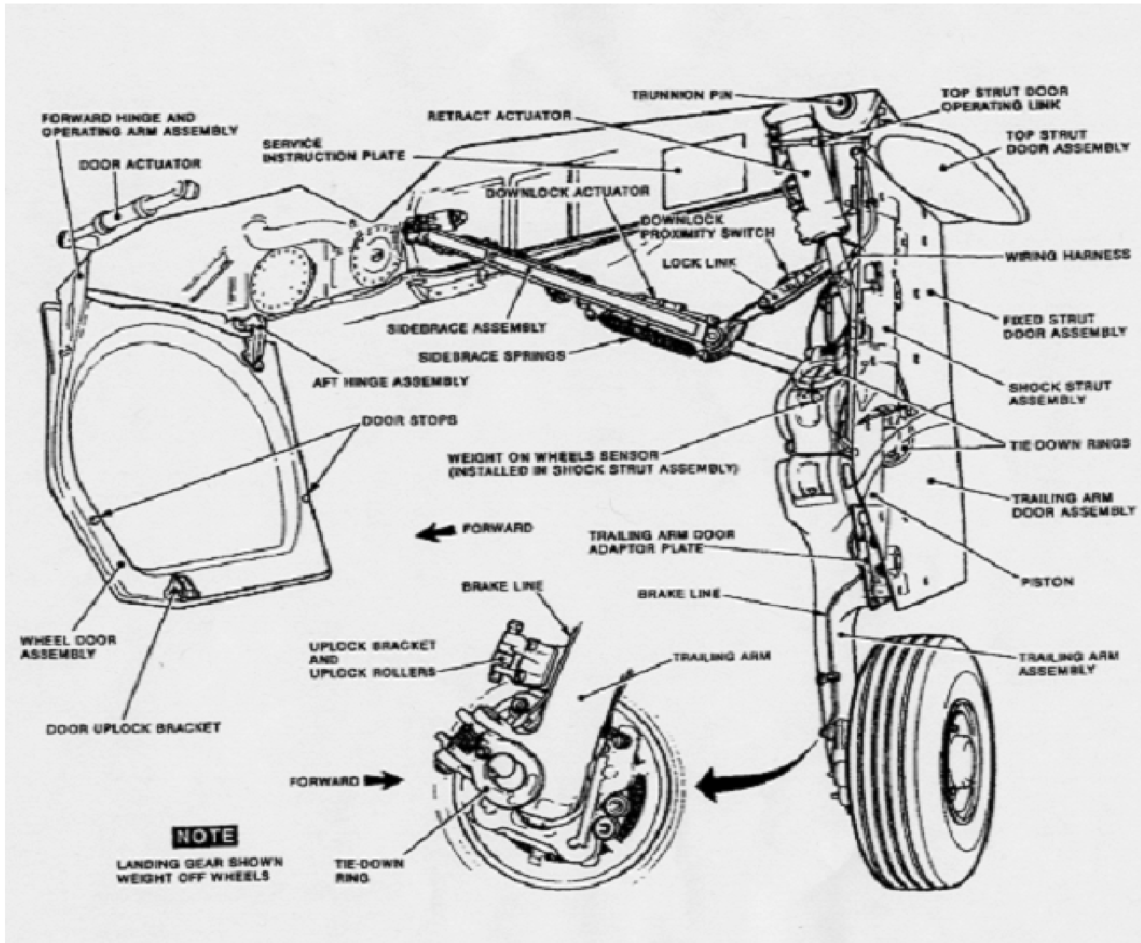


Figure 5: MAIN LANDING GEAR AND DOORS
(Technical Manual, Reference 3)

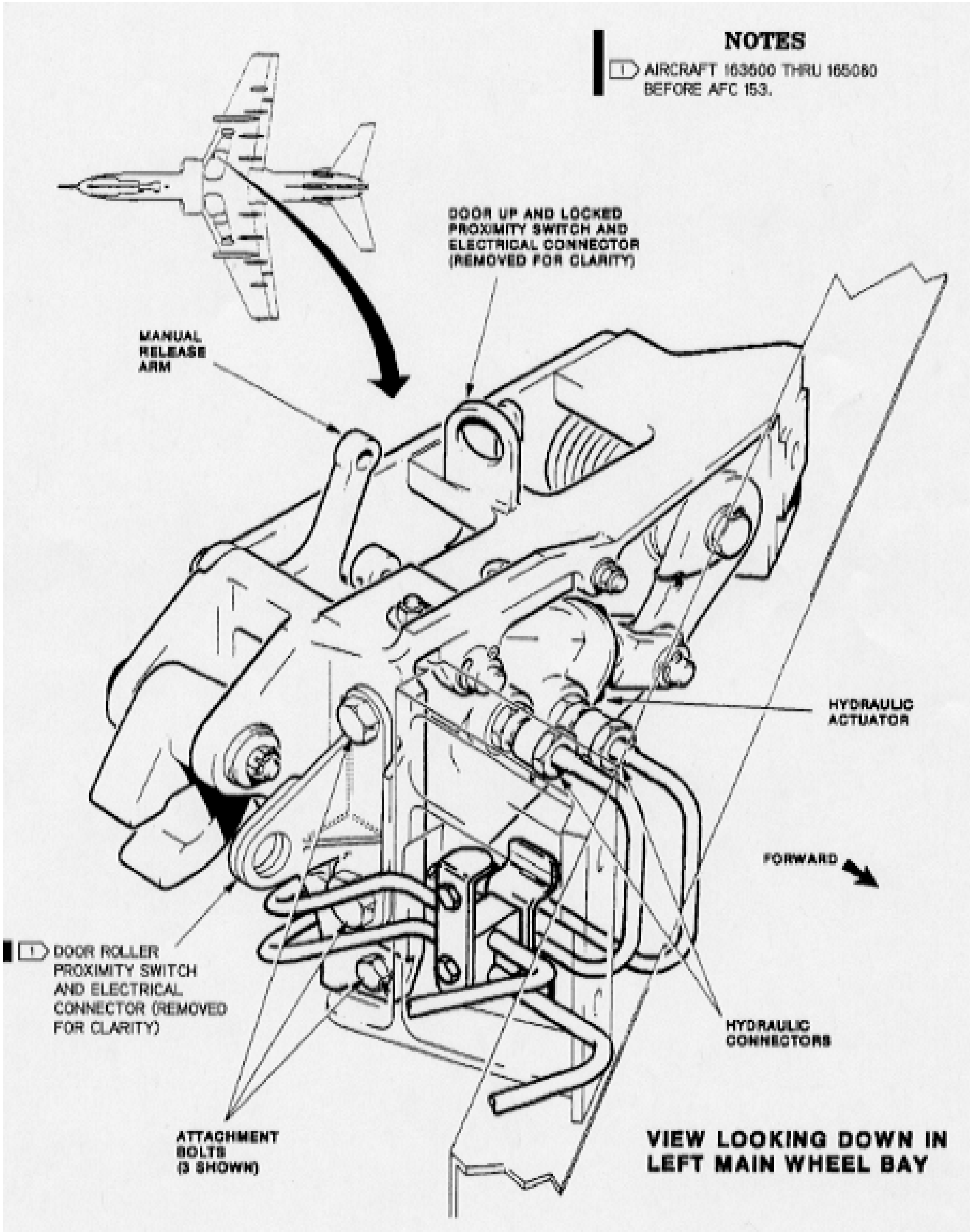


Figure 6: MAIN LANDING GEAR WHEEL DOOR UPLOCK ACTUATOR AND UPLOCK (Technical Manual, Reference 3)

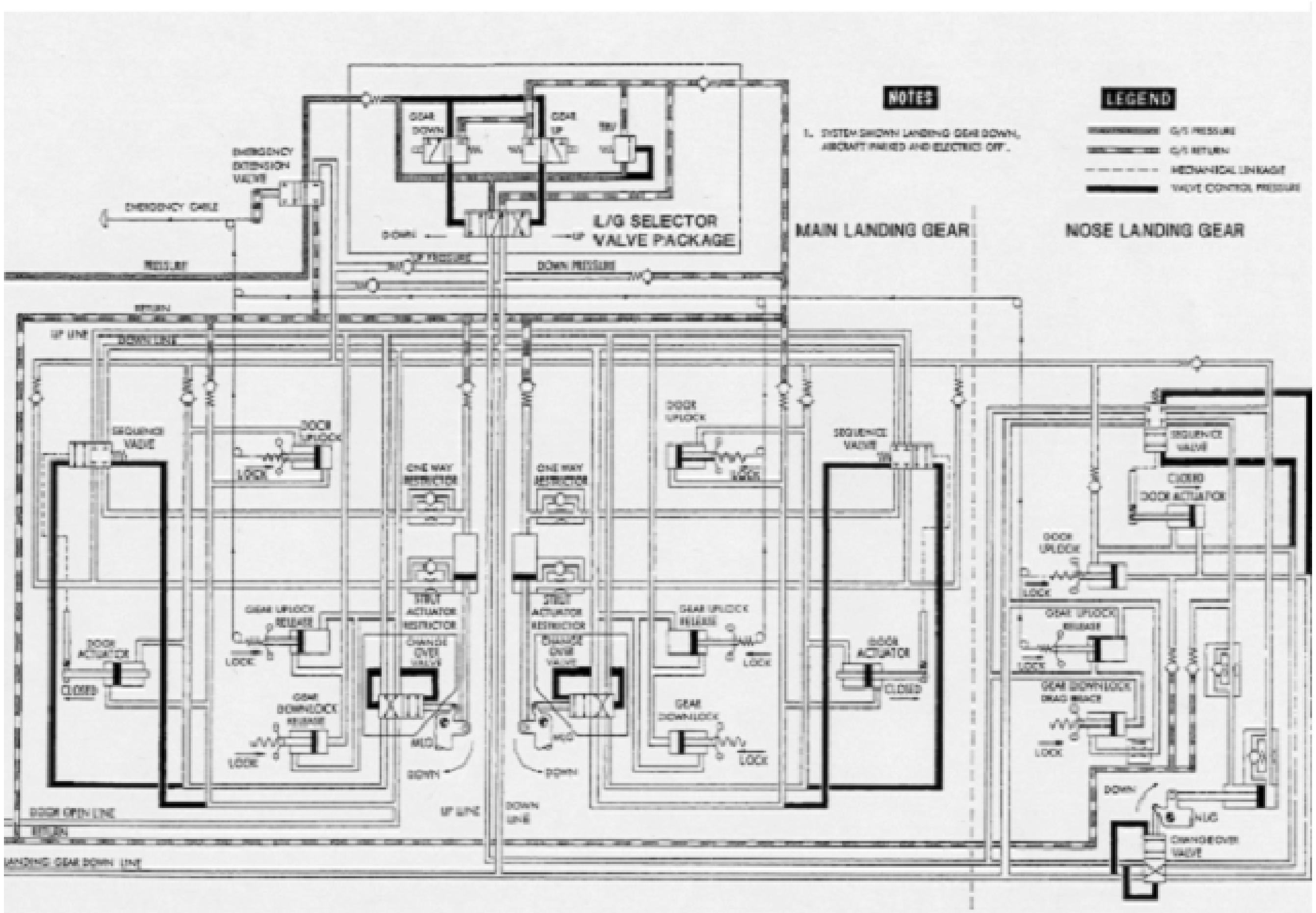


Figure 7: LANDING GEAR - HYDRAULIC CIRCUIT SCHEMATIC – MLG
(NATOPS, Reference 1)

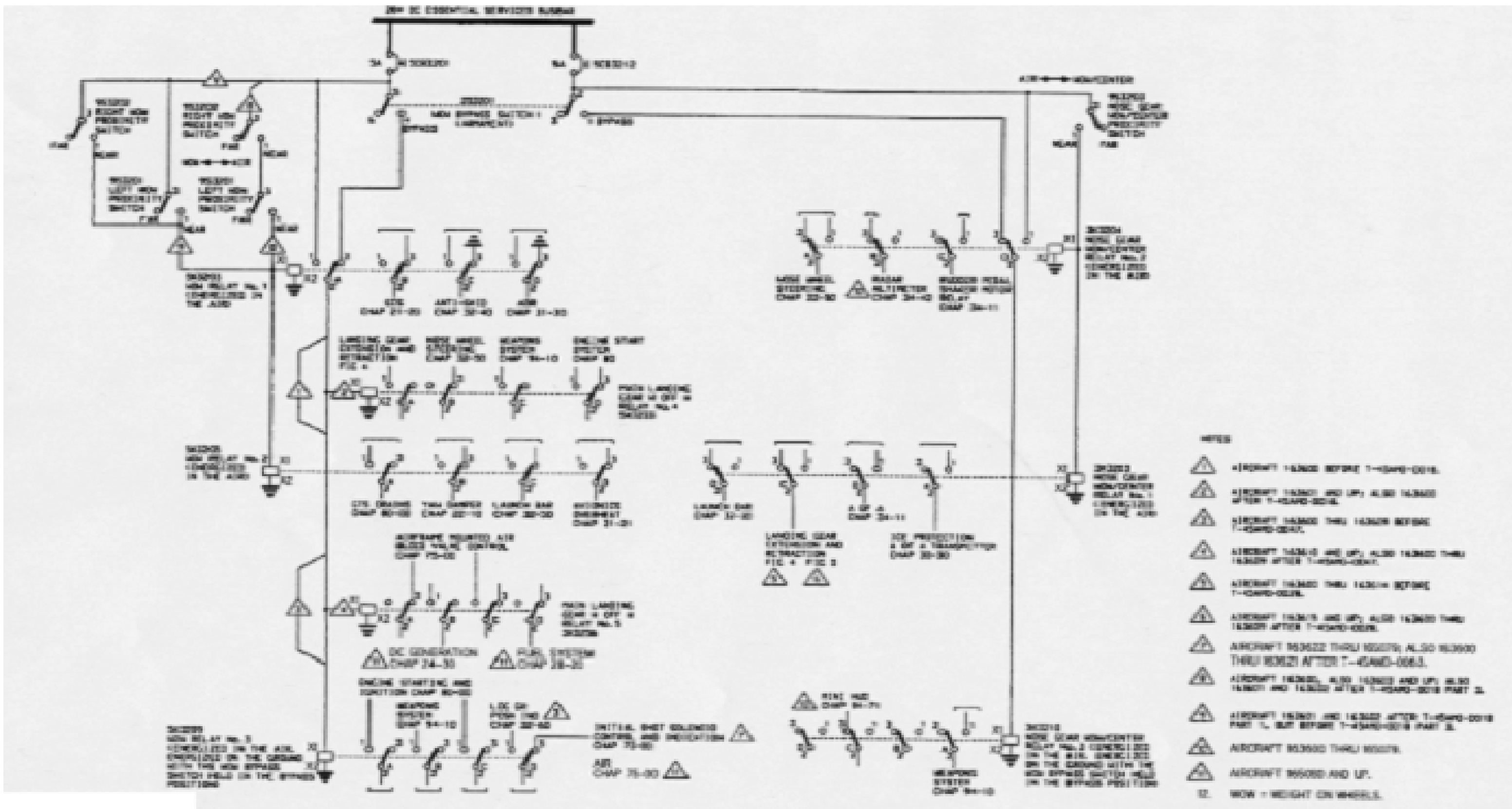


Figure 8: LANDING GEAR – WEIGHT ON WHEELS ELECTRICAL SCHEMATIC
(NATOPS, Reference 1)

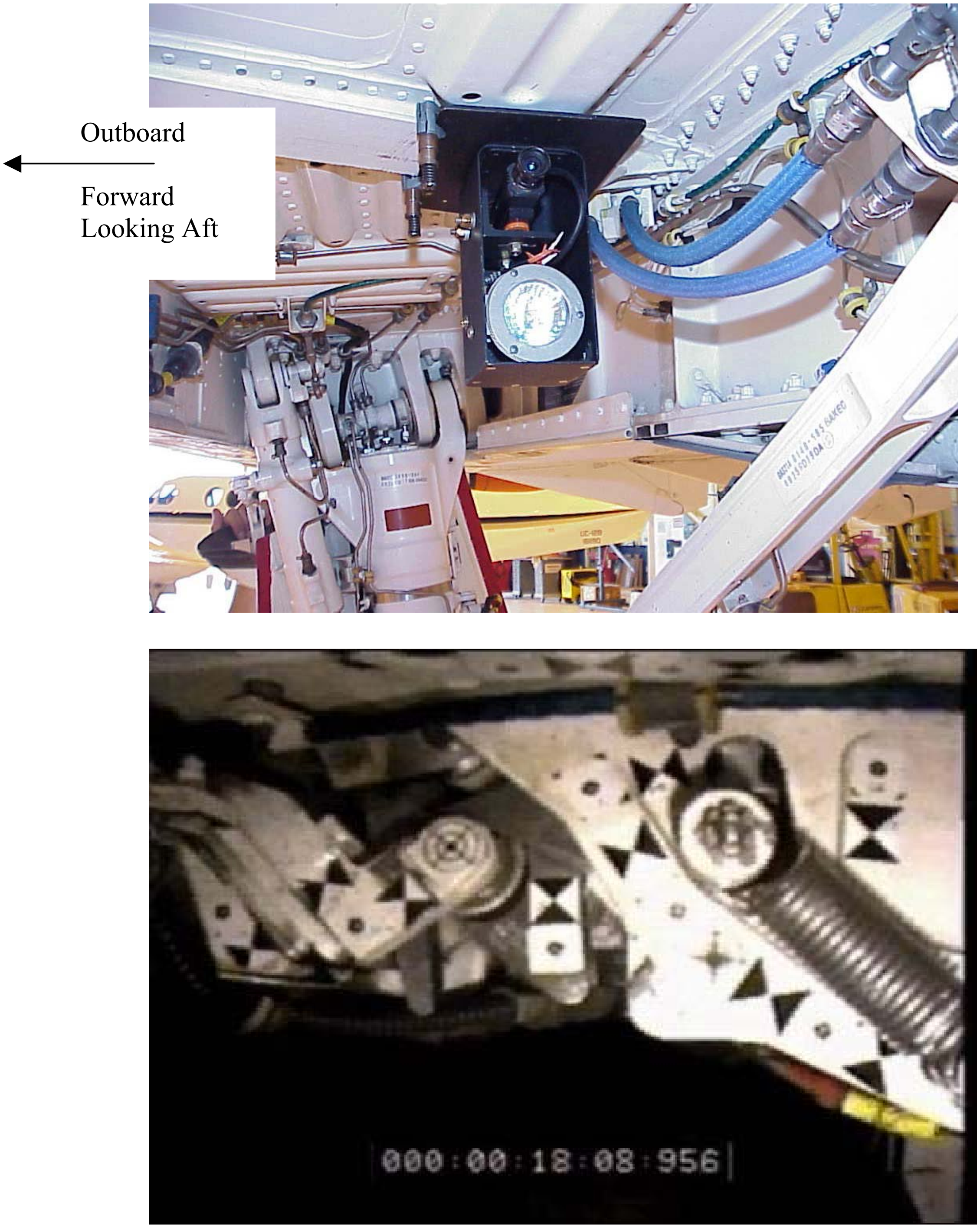
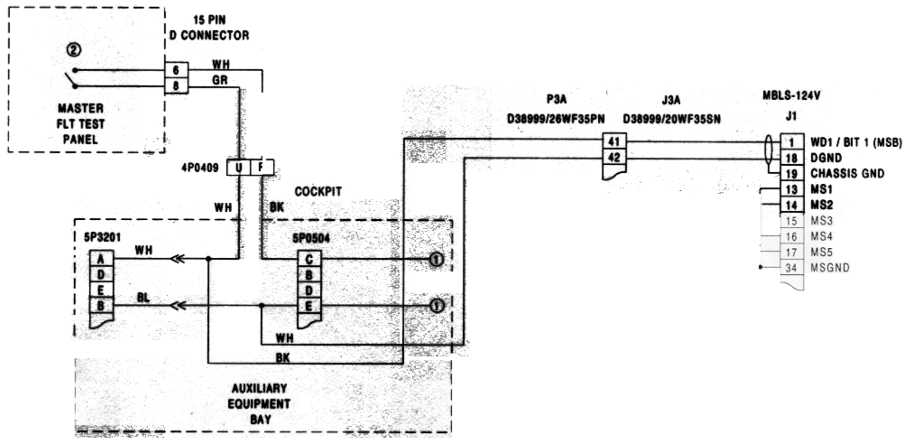


Figure 9: LEFT MLG CAMERA INSTALLATION (TOP)
AND UPLOCK VIEW FROM CAMERA (BOTTOM)



NOTES:

1. CONTINUED ON BOEING SCHEMATIC DA920M7532
2. SWITCH SHOWN IN "DISABLE" POSITION

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T-45C, 163635

LANDING GEAR SELECT VALVE
DISABLE & DISCREET

18 JUN, 2001 M.W. HEPP SHEET 1 OF 1

BORDER.DW2

Figure 10: LANDING GEAR SELECTOR VALVE MODIFICATION SCHEMATIC

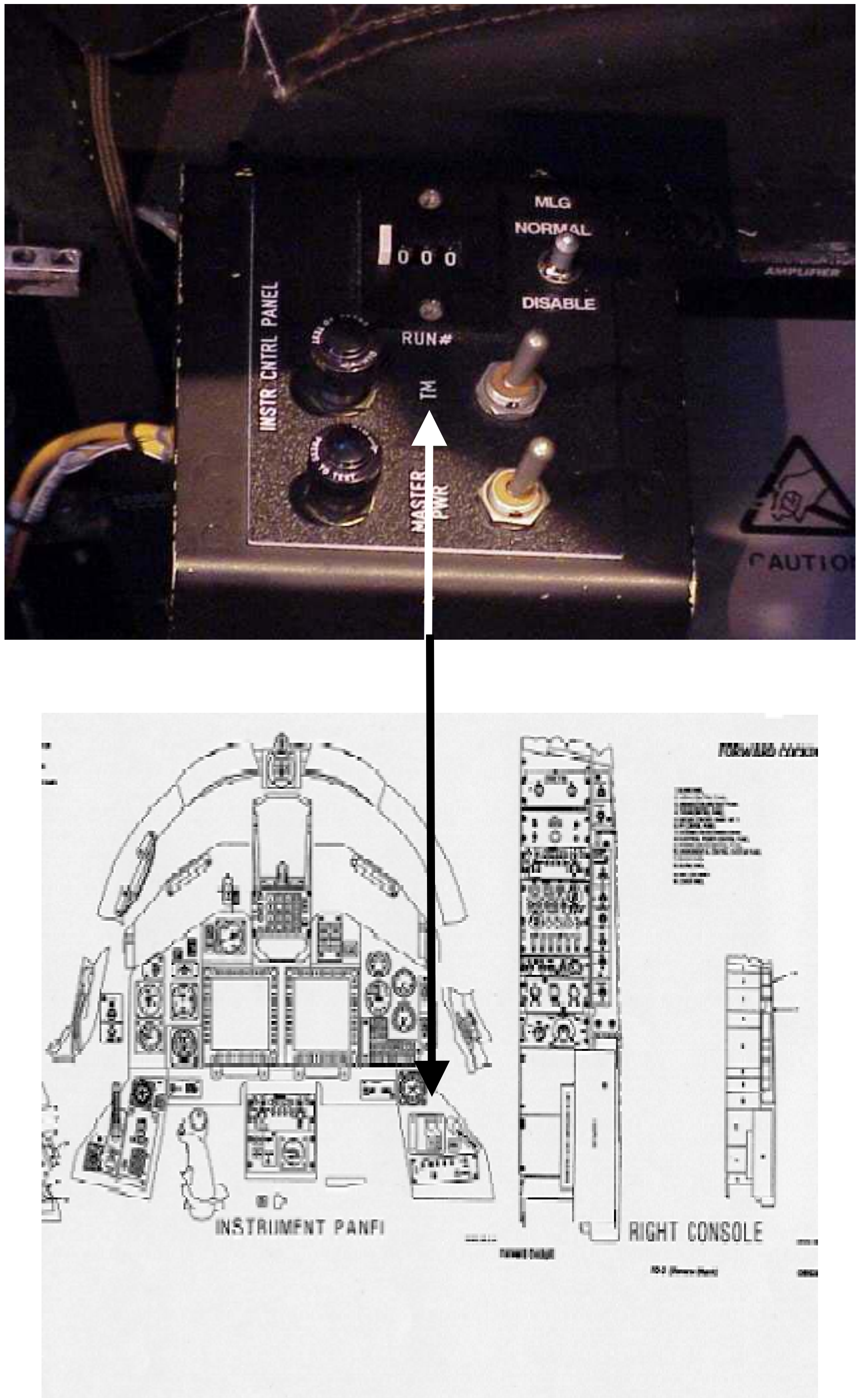

Figure 11: CONTROL SWITCH INSTALLATION IN FORWARD COCKPIT

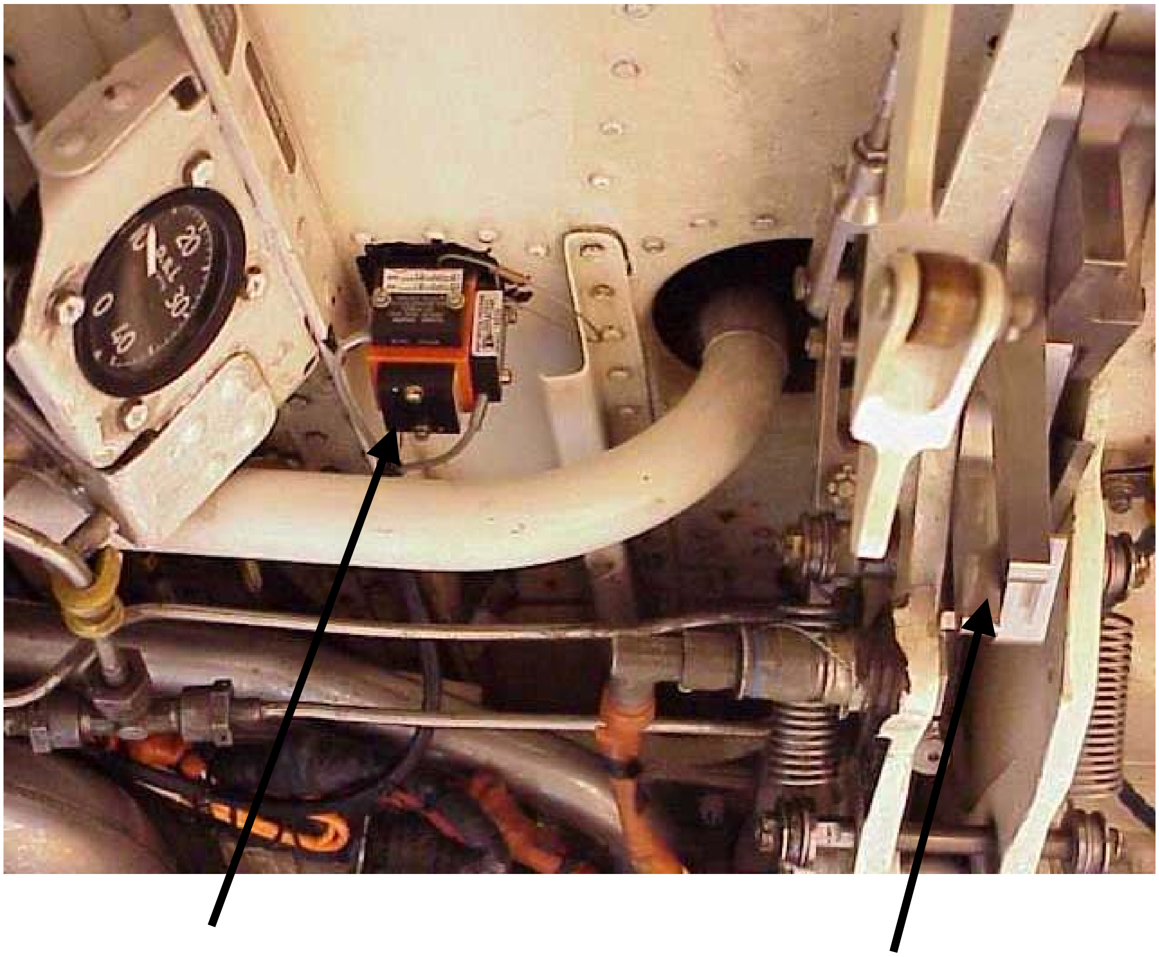

Figure 12: WING ACCELEROMETER BLOCK INSTALLATION

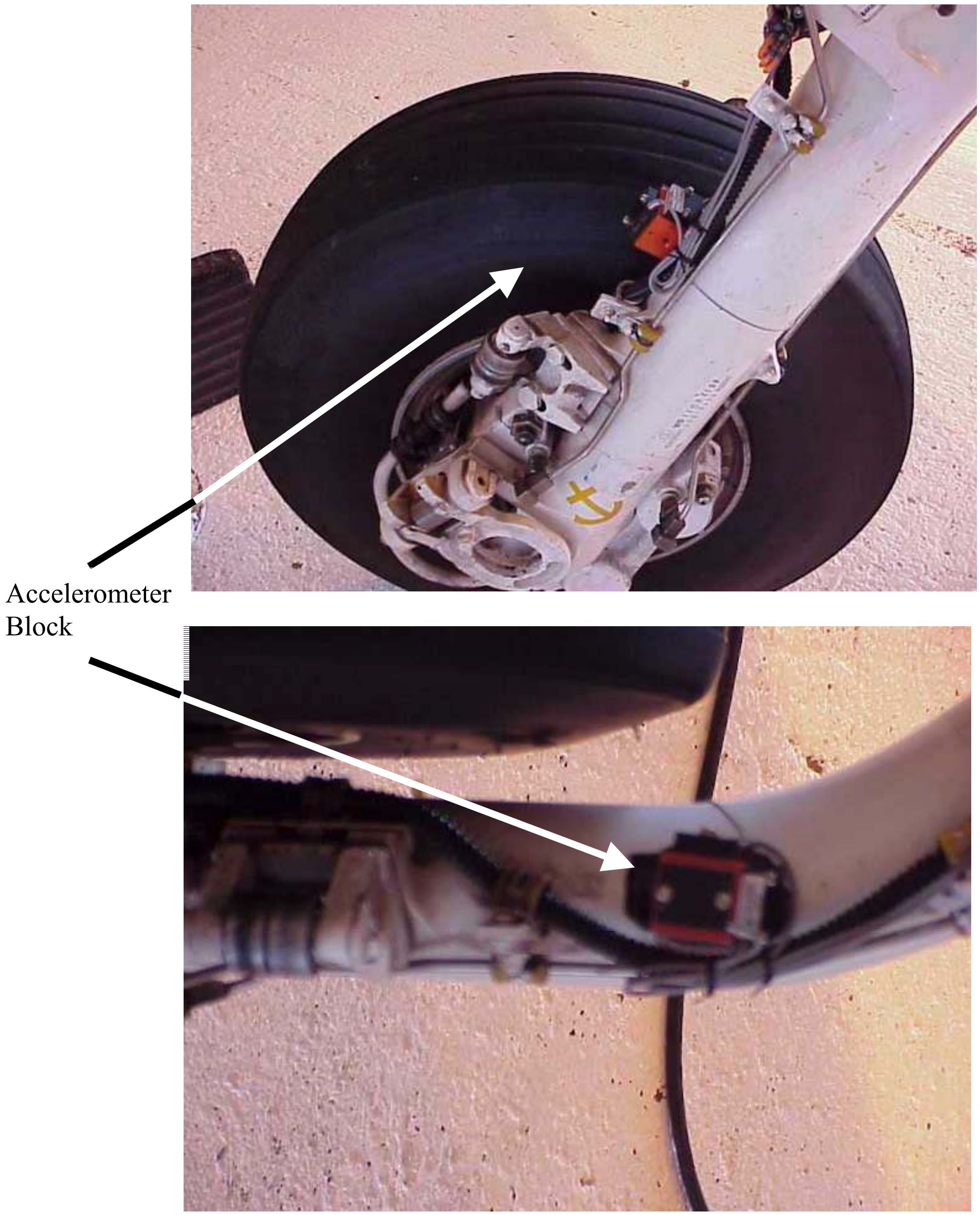

Figure 13: LANDING GEAR ACCELEROMETER INSTALLATION

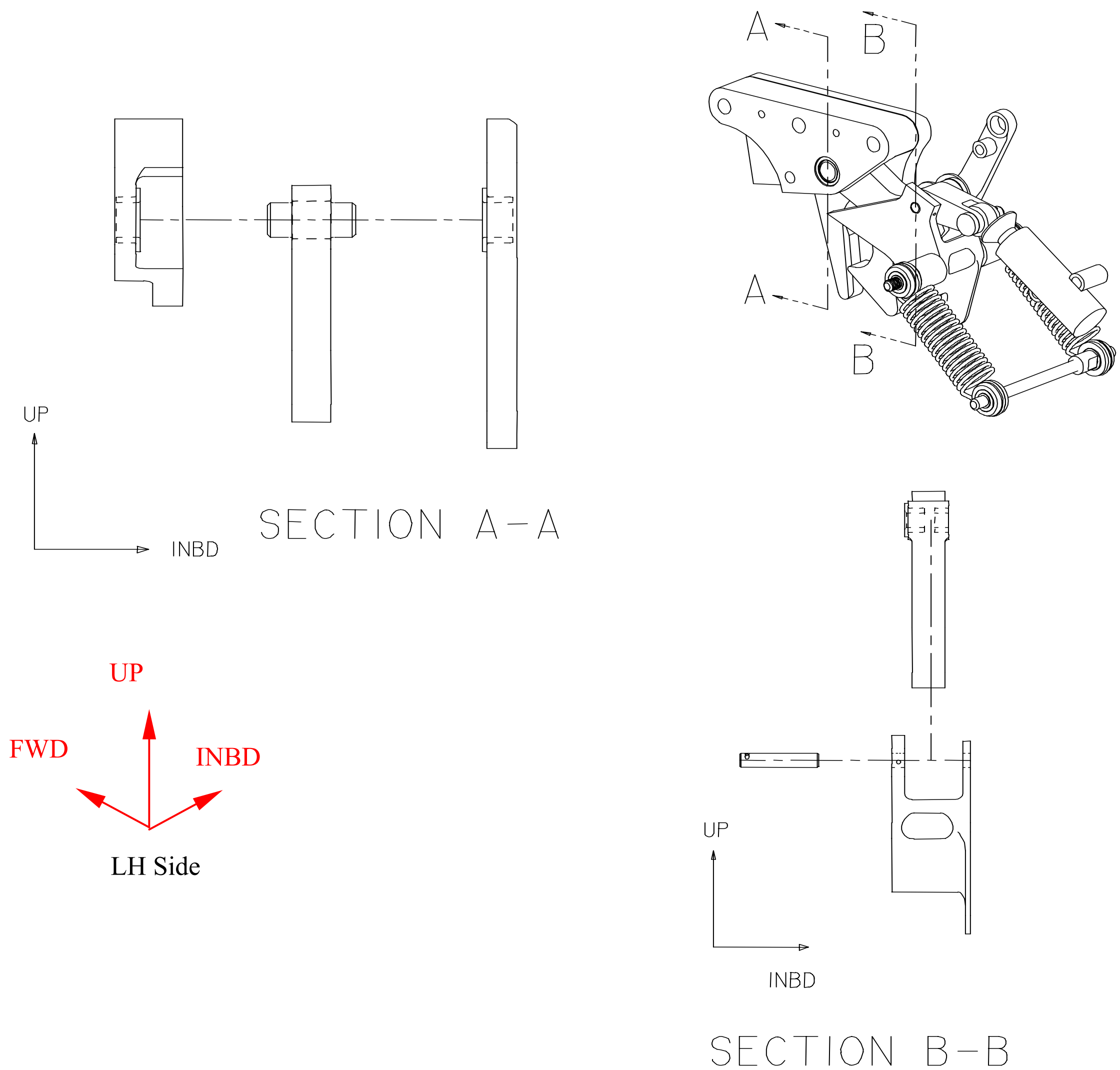

Figure 14: TARGET LINK ASSEMBLY

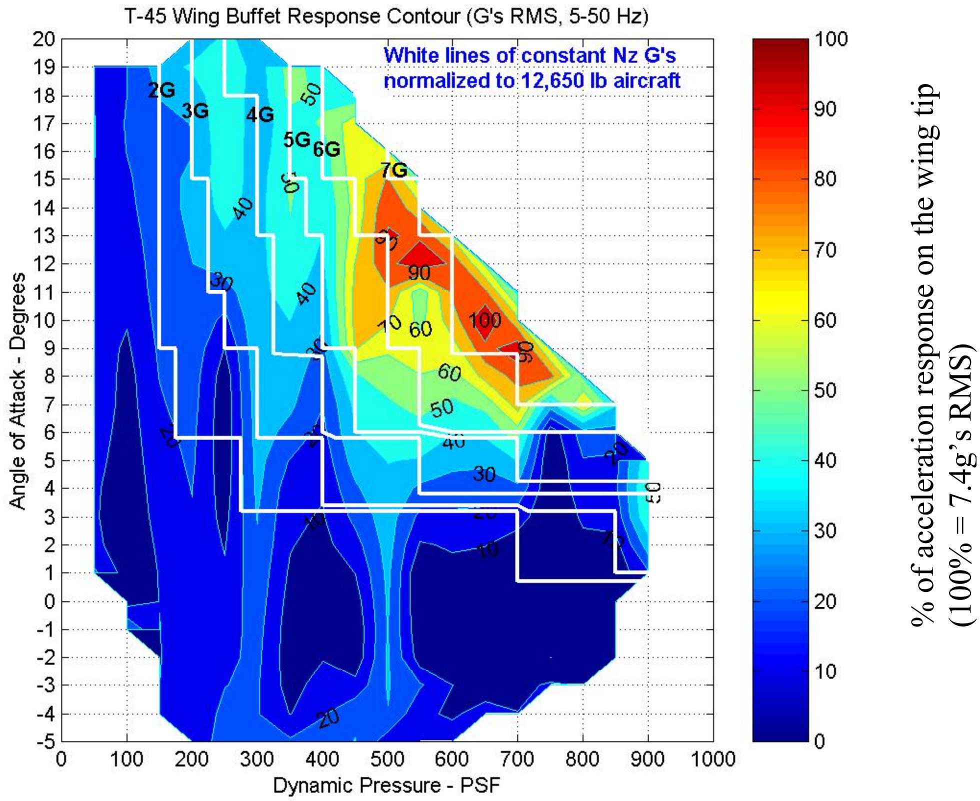

Figure 15: T-45 WING BUFFET RESPONSE CONTOUR WITH OVERLAY OF NZ-G

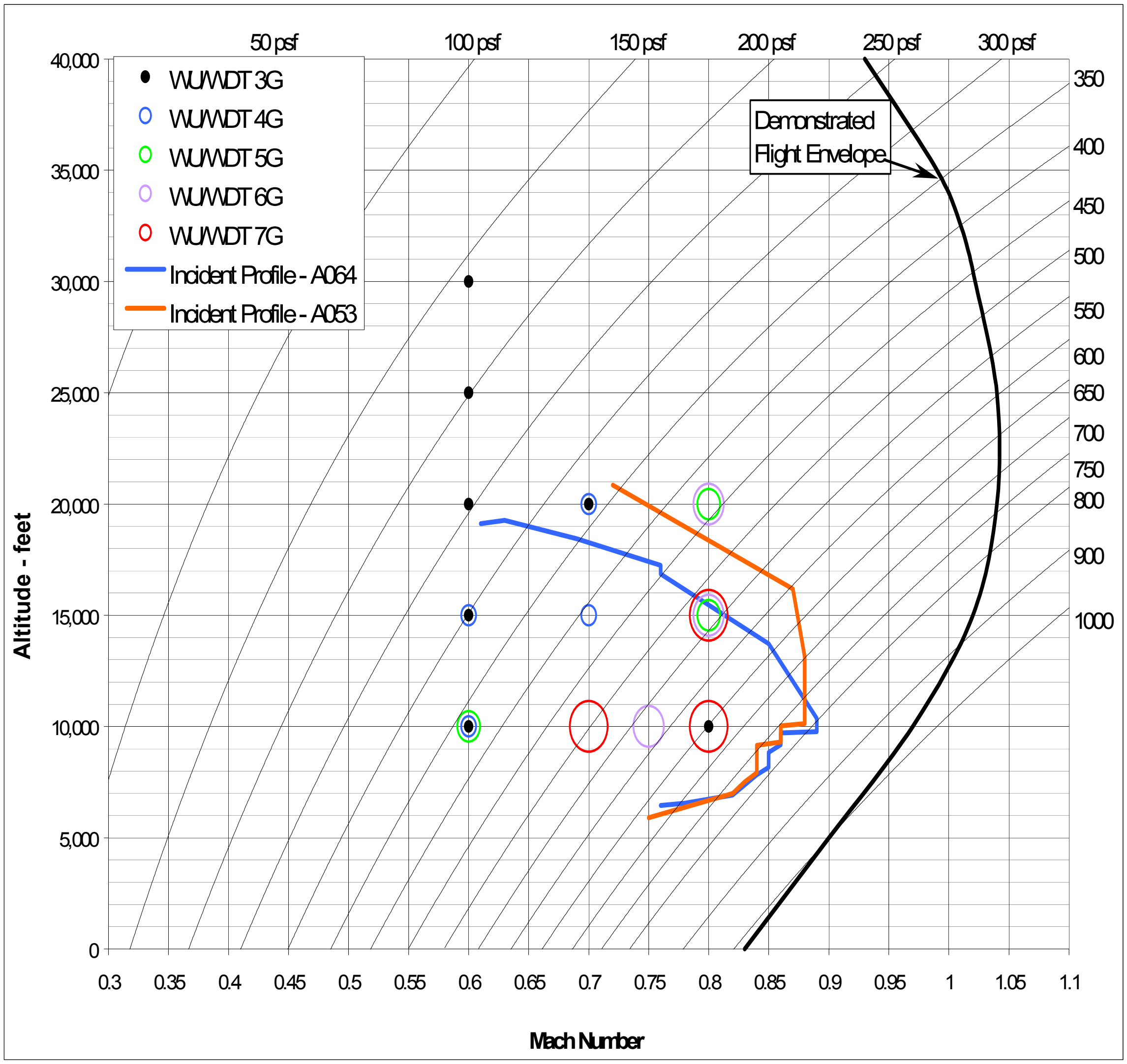

Figure 16: T-45 MAIN LANDING GEAR INVESTIGATION PROPOSED FLIGHT PROFILE

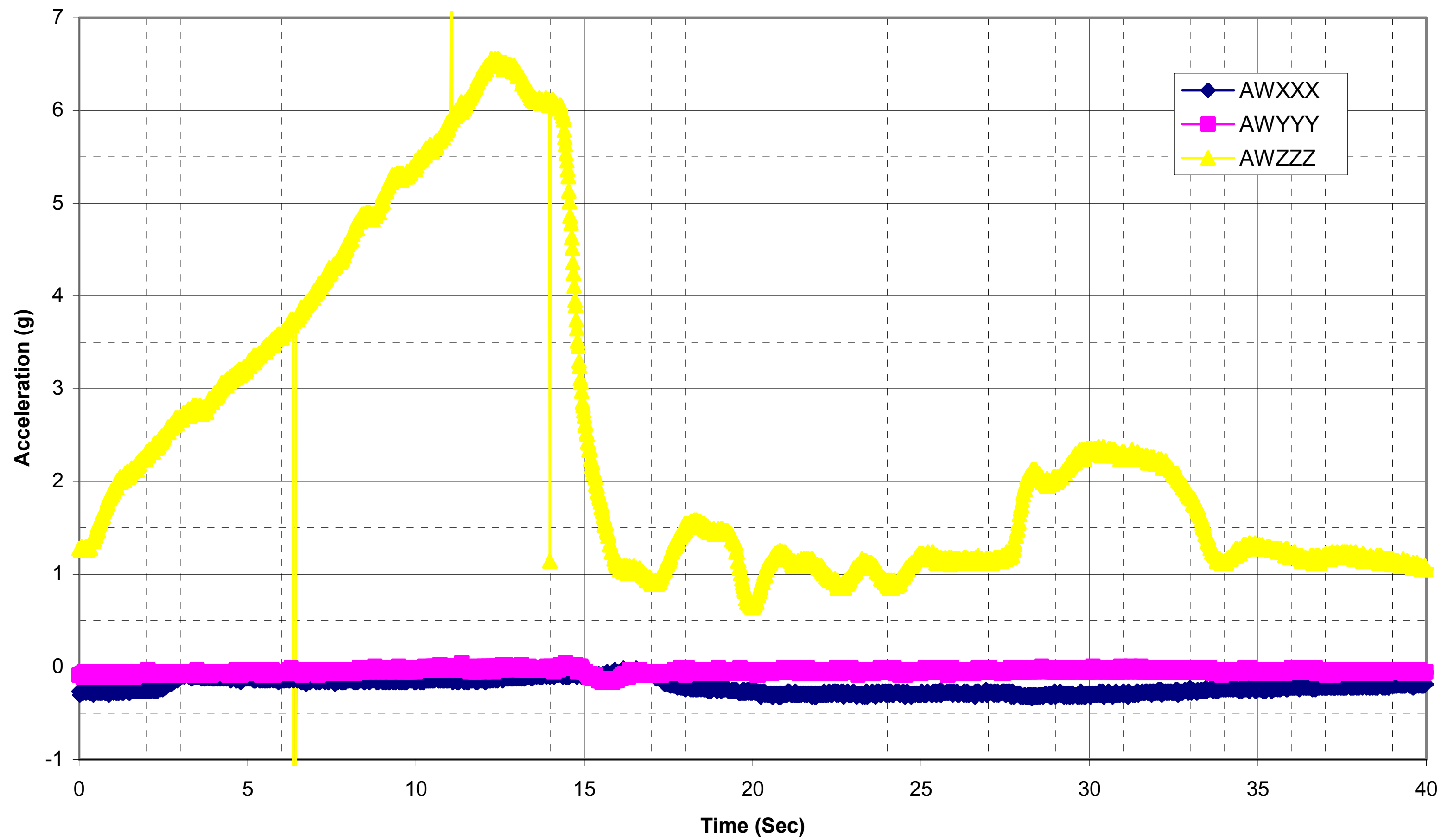

Figure 17: WING ACCELERATION VALUES DURING POINT WITH SPRING MOTION
(TP2-19, FLT 1620)

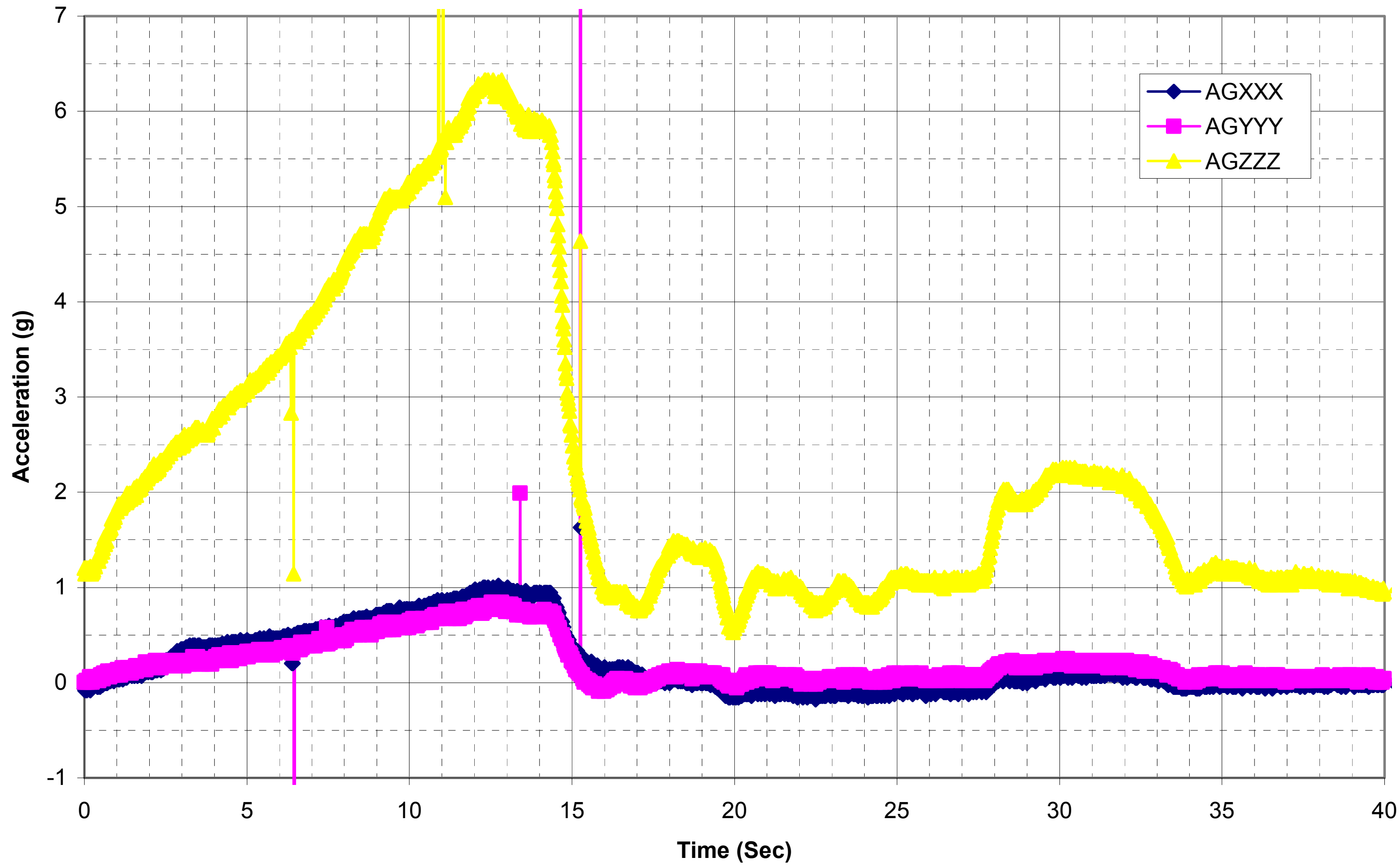

Figure 18: GEAR ACCELERATION VALUES DURING POINT WITH SPRING MOTION (TP 2-19, FLT 1620)

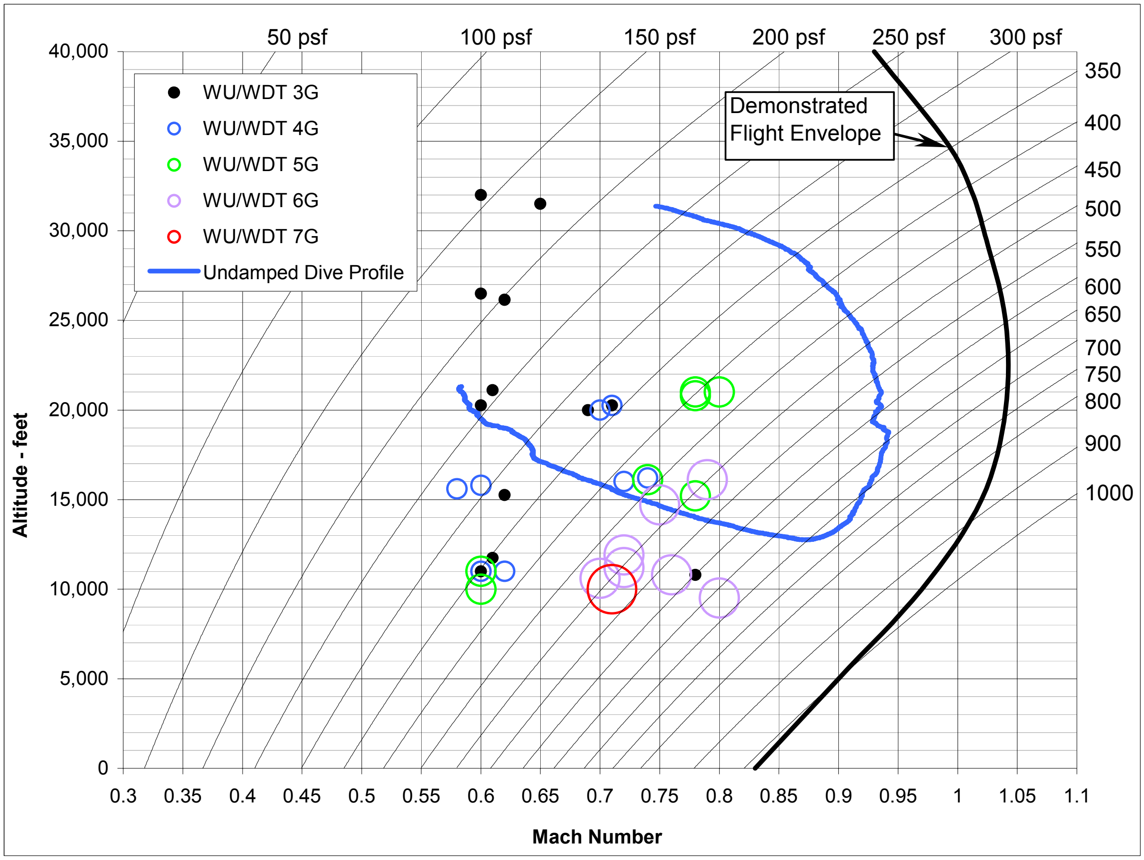

Figure 19: UNDAMPED MAIN LANDING GEAR COMPLETED TEST POINTS

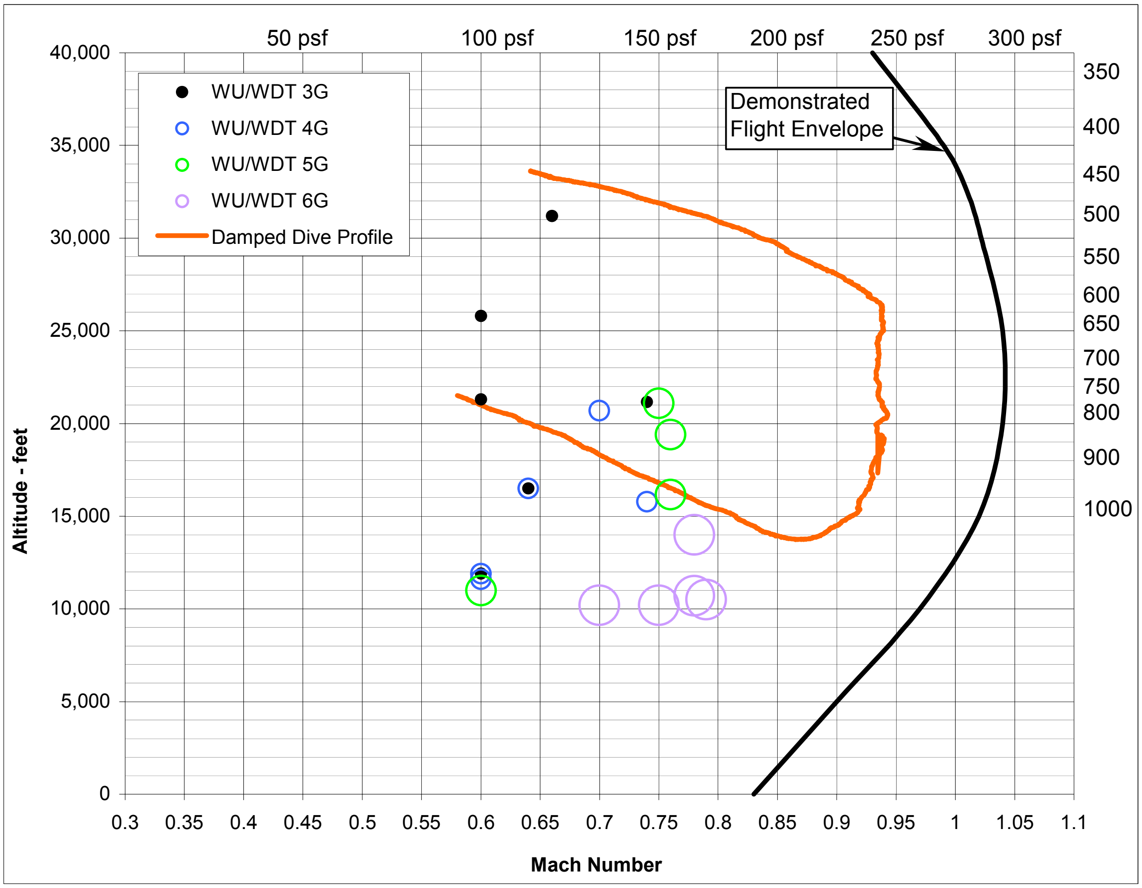

Figure 20: DAMPED MAIN LANDING GEAR COMPLETED TEST POINTS

Figure 21: FLT 1611 HYDRAULIC PRESSURE CHANGES
(Note1: Double click to play video)
(Note 2: Time stamp is incorrect on video)

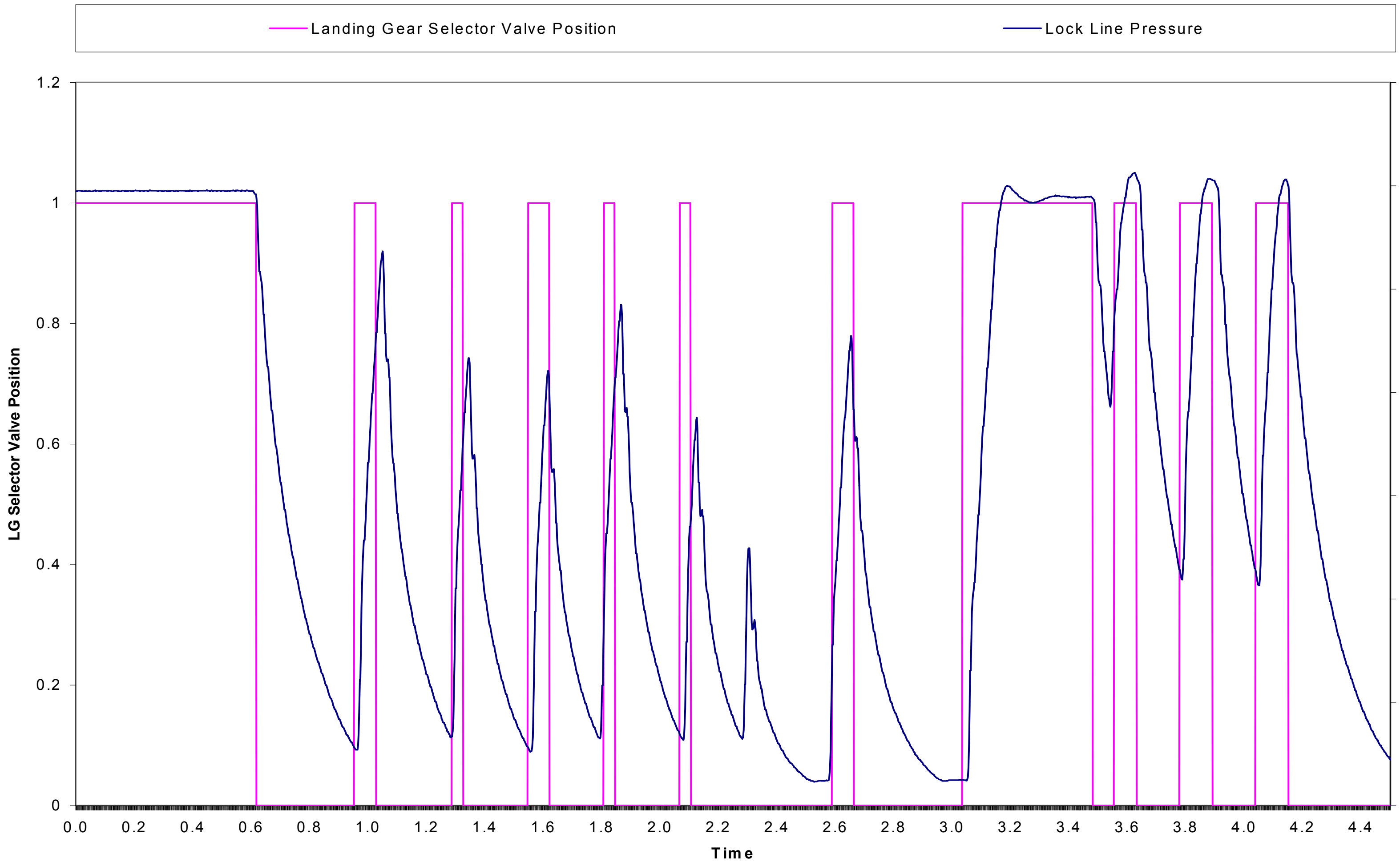

Figure 22: LOCK LINE PRESSURE DURING TEST POINT 4-6, SWITCH TOGGLED TO DISABLED POSITION
(Note: Position 1: Gear Retracted, Position 0: Gear Extended

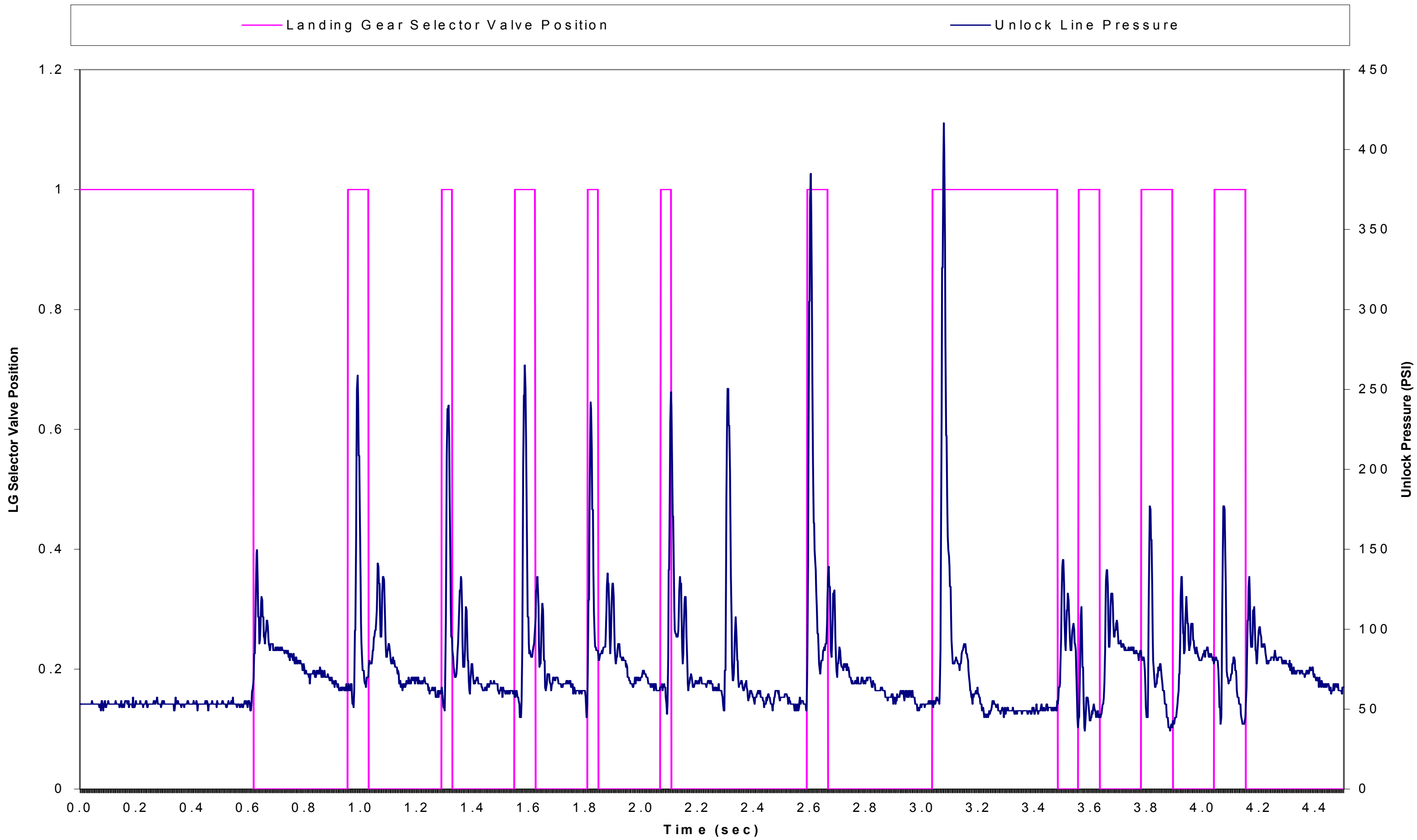

Figure 23: UNLOCK PRESSURE DURING TEST POINT 4-6, SWITCH TOGGLED TO DISABLED POSITION
(Note: Position 1: Gear Retracted, Position 0: Gear Extended)

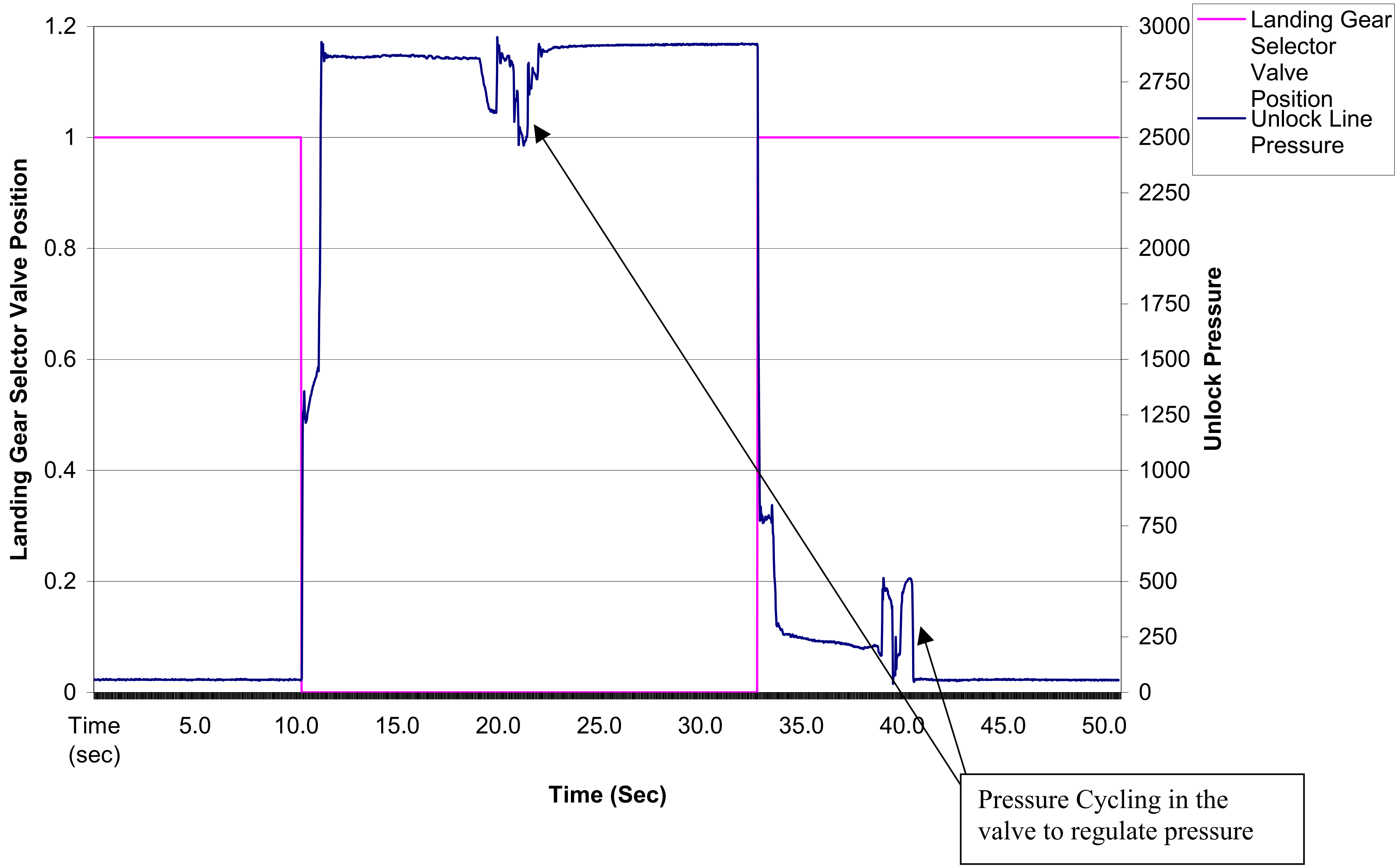

Figure 24: NORMAL LANDING GEAR EXTENSION UNLOCK LINE PRESSURE (TEST POINT 4-1)
(Note: Position1: Gear Extended, Position 0: Gear Extended)

APPENDIX B:
LANDING GEAR DOOR STRUCTURAL ANALYSIS PREFORMED BY BOEING STRUCTURAL GROUP

THE WHEEL DOOR WAS DESIGNED TO THE LOADS DEFINED IN MDC K 2218 VOL V BOOK 12. THE CRITICAL DESIGN CONDITION IS FOR A -3 "G" MANEUVER

THE FOLLOWING ANALYSIS DETERMINED IF THE WHEEL DOOR COULD SUPPORT THE MLG SHOULD THE MLG UPLOCK FAIL AND THE MLG RETRACT ACTUATOR HYDRAULIC POWER WOULD BE LOSS. RESULTS SHOW THAT THE WHEEL DOOR WILL SUPPORT THE GEAR FOR AIRCRAFT MANEUVERING UP TO 7.3 g's

JUN 07 '01 13:24 FR F15-AVBB-T45TS H-LG-M314 232 9487 TO 813013424453 P.02/08

DAC 25-2216 (3-81)

PREPARED BY: BAE BROUGH (ICAP/LLS) MCDONNELL DOUGLAS CORPORATION PAGE: V-12-1-5

DATE: OCT. 1986 MODEL: T45A

TITLE: T45A STRENGTH ANALYSIS (MLG DOORS) REPORT NO.: MDC K2218

CHANGE LETTER(S): VOLUME NO.: V

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Page 1

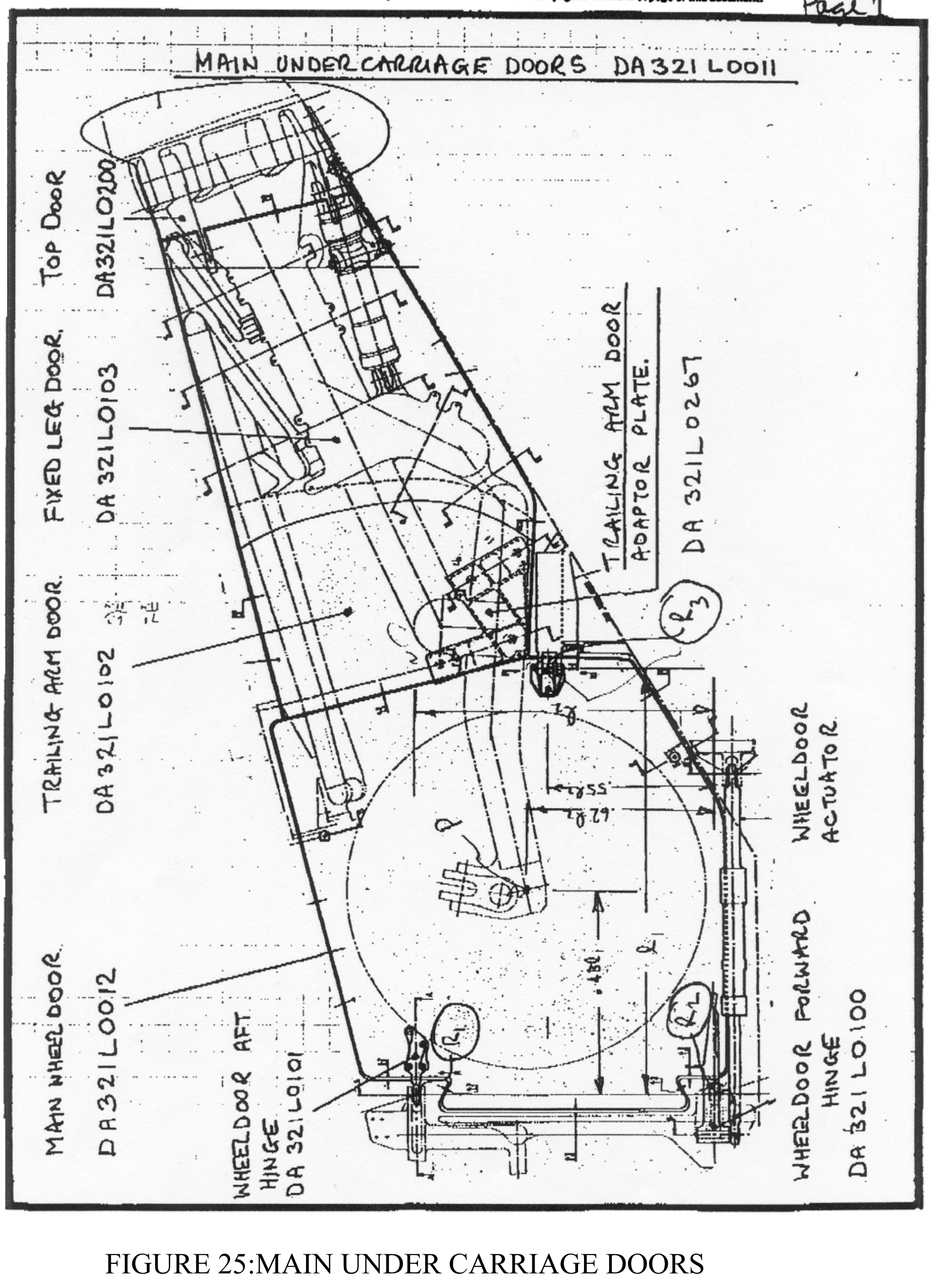
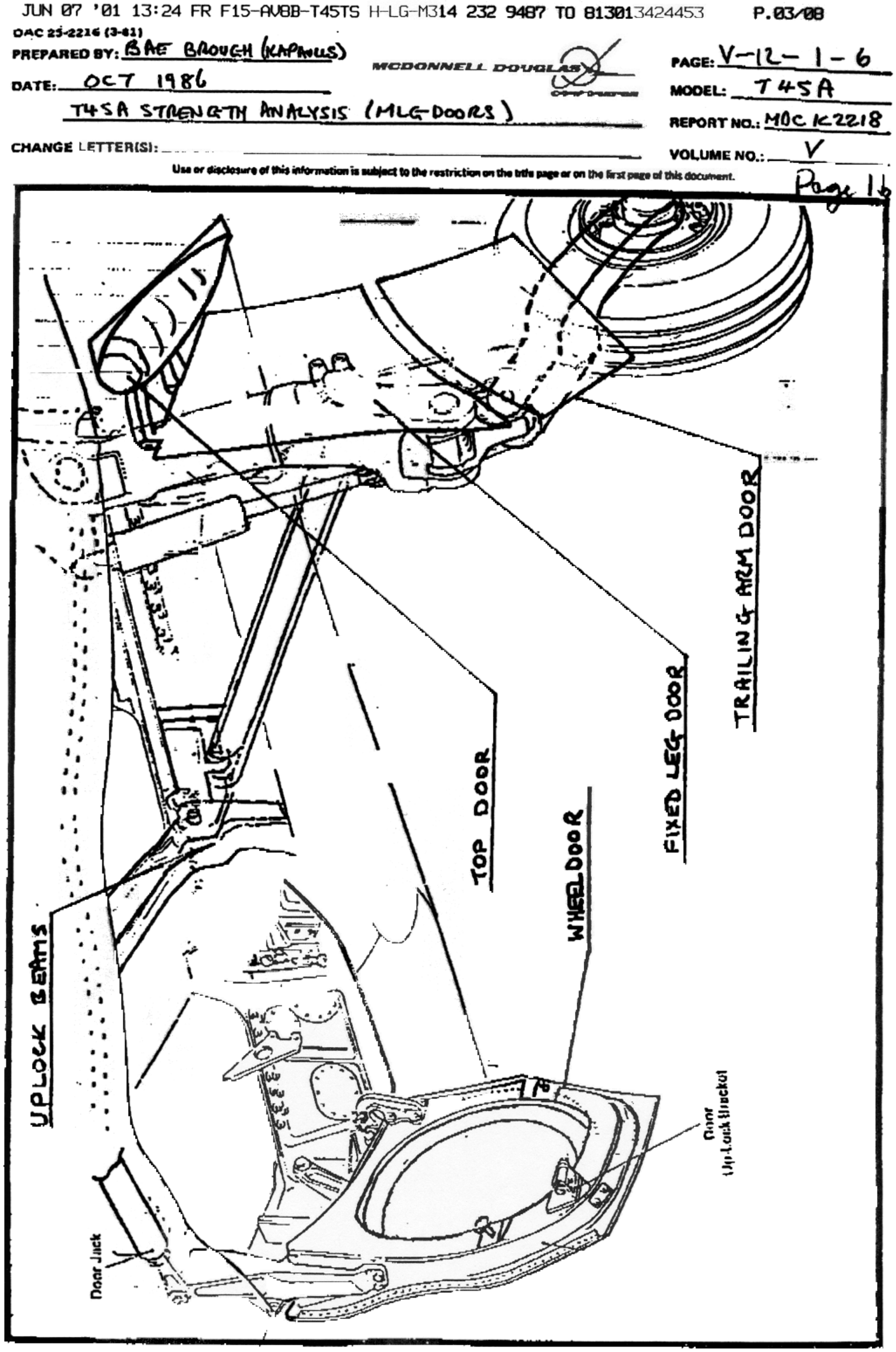


FIGURE 25:MAIN UNDER CARRIAGE DOORS


JUN 07 '01 13:24 FR F15-AV8B-T45TS H-LG-M314 232 9487 TO 813013424453 P.03/08

DAC 25-2216 (3-81)

PREPARED BY: BAE BROUGH (KAPAULS) MCDONNELL DOUGLAS PAGE: V-12-1-6

DATE: OCT 1986 MODEL: T45A

T45A STRENGTH ANALYSIS (MLG-DOORS) REPORT NO.: MDC K2218

CHANGE LETTER(S): VOLUME NO.: V

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Page 16

Figure 26: MAIN LANDING GEAR DOOR

JUN 07 '01 13:25 FR F15-AV8B-T45TS H-LG-M314 232 9487 TO 813013424453 P.04/08

DAC 25-2216 (3-81)

PREPARED BY: BAe BROUGH (K.PAULS) MCDONNELL DOUGLAS CORPORATION PAGE: V-12-14-1

DATE: OCTOBER 1986 MODEL: T45A

TITLE: T45A STRENGTH ANALYSIS (WHEEL DOOR) REPORT NO.: MDCK 2218

CHANGE LETTER(S): VOLUME NO.: V

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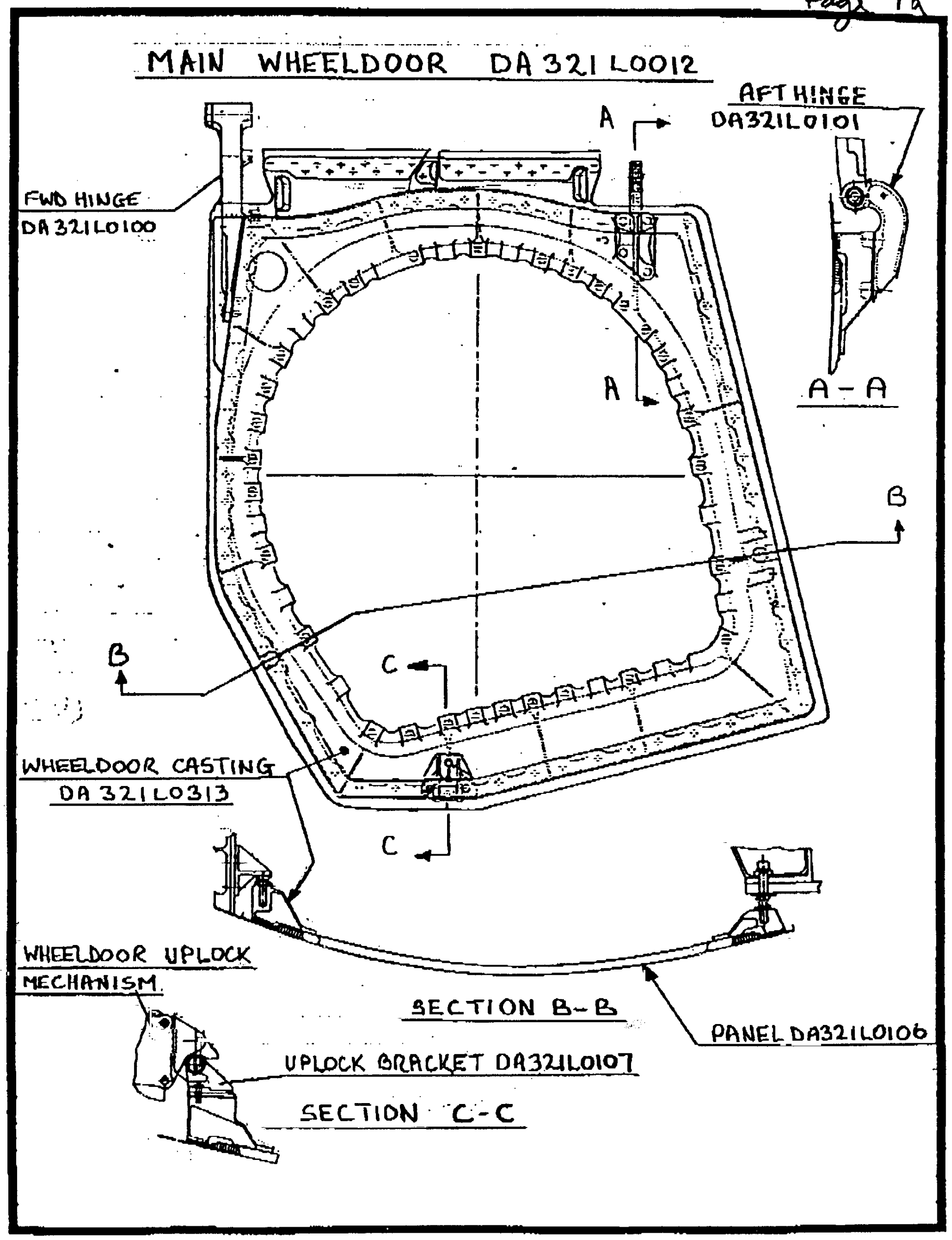


Figure 27: MAIN WHEEL DOOR

The MLG wheel door critical design condition is for the door closed and airloads from maneuver. The resulting door hinge loads are as follows:

- AFT HINGE Ref MDC K2218, Page V-12-14-41
  P_{LOAD} = 17.3KN or 3892.5 lbs

  FWD HINGE Ref MDC K2218, Page V-12-14-80
  P_{LOAD} = 7.053KN or 1587 lbs

  UP LOCK BRACKET Ref MDC K2218, Page V-12-14-42
  P_{LOAD} = 22.8KN or 5130 lbs

Determine the door support reaction loads for a unit "1G" wheel load applied to the door. Ref page 1 for MLG wheel hub location with respect to the door's support

R_1 = reaction @ aft hinge
reaction @ fwd hinge
R_3 = reaction @ outbd bracket

SUMMARY OF FORCES

$R_1 + R_2 + R_3$ = WHEEL HUB LOAD,

Σ MOMENT ALONG HINGE LINE = 0, Ref Page 1

$.48 \ell_1 \times P - R_3 \ell_1 = 0$

$\underline{R_3 = .48P}$

Σ MOMENT NORMAL TO HINGELINE = 0

$.62 \ell_2 P - R_1 \ell_2 - R_3 \times .55 \ell_2 = 0$

$.62P - .264P = R$

$\underline{R_1 = .356P}$

$R_2 = (1 - .48 - .356) P = \underline{.164P}$

DETERMINE WHEEL HUB LOAD AT "1G", ASSUMING NO HYDRAULIC POWER & NO MLG UPLOCK CAPABILITY.

- WT OF GEAR = 1602 N or 360

DISTANCE OF GEAR'S C.G. TO TRUNNION SUPPORT = 888.4 mm or 34.98 IN

DISTANCE OF HUB TO TRUNNION SUPPORT = 1448.77mm or 57.04 IN

LOAD, P PER "G" = (1602 × 888.4)/1448.77 = 982.4N/g or 221 lbs/g

DOOR REACTION BASED ON HUB LOAD

$$R_1 = .356 \times 221 \text{ lbs/g} = 78.7 \text{ lbs/g}$$
$$R_2 = .164 \times 221 \text{ lbs/g} = 36.2 \text{ lbs/g}$$
$$R_3 = .48 \times 221 \text{ lbs/g} = 106.1 \text{ lbs/g}$$

ASSUME THE CURRENT MARGINS OF SAFETY ARE ZERO AT EACH HINGE LOCATION, DETERMINE "G" LEVEL FOR WHEEL RESTING ON DOOR TO CAUSE EQUAL HINGE REACTION AS NOTED FOR THE -3G AIR LOAD CONDITION:

AFT HINGE CAPABILITY

ALLOWABLE "G" = $3892.5^{\#} / 78.7^{\#}/g$ = 49g's

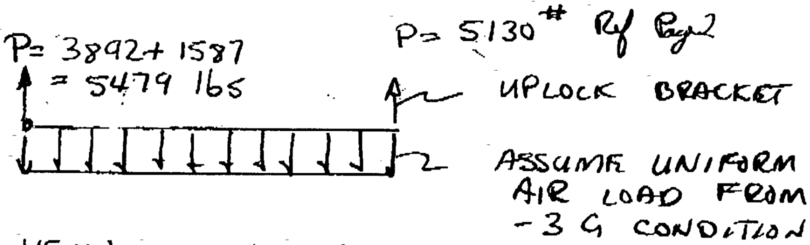
FWD HINGE CAPABILITY

ALLOWABLE "G" = $1587^{\#} / 36.2^{\#}/g$ = 43g's

UPLOCK BRACKET CAPABILITY

ALLOWABLE "G" = $5130^{\#} / 106.1^{\#}/g$ = 48g's

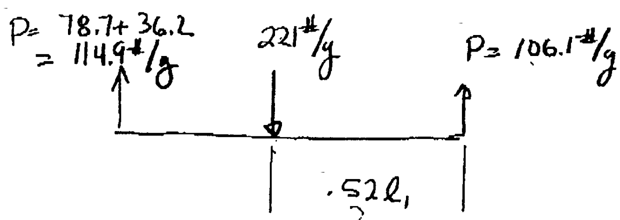
DETERMINE "G" LOADING TO DEVELOP EQUIVALENT DOOR BENDING MOMENT ACROSS DOOR FOR −3 G AIR LOAD CONDITION



VEIW LOOKING AFT

$$\text{MAX DOOR BENDING MOMENT} = \tfrac{1}{2}(5130)(\ell_1/2)$$

$$= \underline{1282.5\ell_1} \text{ ALLOWABLE}$$



$$\text{MAX DOOR BENDING MOMENT} = \frac{106.1^{\#}}{g} \times .52\ell_1$$

$$= \frac{55.2^{\#}\ell_1}{g}$$

ALLOWABLE "G" ASSUME MARGIN OF SAFETY IS ZERO: $\text{"G"} = \dfrac{1282.5^{\#}\ell_1}{55.2^{\#}\ell_1} \times g = \underline{\underline{23.2\ g\text{'s}}}$

APPENDIX C:
TEST POINT MATRIX

Table 4
TEST POINT MATRIX

Test Point	Test Point Description	Aircraft Config	Altitude (ft MSL)	Airspeed (KIAS)	Mach	Nz (g's)	Q (psf)	Cockpit Switch Position	Switch Duration (seconds)	Comments
GROUND TEST										
OVER-CENTER DISTANCE										
1-1	Gear Swing		Surface	N/A	N/A		N/A	DISABLE	N/A	Document latch engagement position with video-camera and scales and calculate over-center distance
FLIGHT 1606										
UNDAMPED DYNAMICS										
2-1	Push Over	CR	12,250	180	0.34	0.5	108	DISABLE		
2-3	WUT	CR	32,000	230	0.60	2.8	145	DISABLE	See Note 1	
2-4	WUT	CR	26,500	250	0.60	3.2	186	DISABLE	See Note 1	
2-5	WUT	CR	20,250	275	0.60	3.0	243	DISABLE	See Note 1	
2-6	WUT	CR	15,250	310	0.62	3.0	319	DISABLE	See Note 1	
2-7	WUT	CR	15,800	300	0.60	3.7	292	DISABLE	See Note 1	
2-8	WUT	CR	11,750	330	0.61	3.0	355	DISABLE	See Note 1	
2-9	WUT	CR	11,000	345	0.62	4.0	377	DISABLE	See Note 1	
2-10	WUT	CR	10,000	335	0.60	5.0	367	DISABLE	See Note 1	L Camera Light Failed during maneuver, RTB to replace camera light
FLIGHT 1608										
UNDAMPED DYNAMICS										
2-11	WUT	CR	20,000	320	0.69	2.8	325	DISABLE	See Note 1	Combined with 2-12
2-12	WUT	CR	20,000	325	0.70	4.0	334	DISABLE	See Note 1	
2-13	WUT	CR	20,800	365	0.78	4.8	401	DISABLE	See Note 1	

Note 1: During these test points, the cockpit switch was moved from the "NORMAL" position to the "DISABLE" position below gear speed. The aircraft then accelerated to the test condition. After the completion of each test point, the aircraft was slowed down and the switch was returned to the "NORMAL" position to reset the gear.

Table 4 Continued

Test Point	Test Point Description	Aircraft Config	Altitude (ft MSL)	Airspeed (KIAS)	Mach	Nz (g's)	Q (psf)	Cockpit Switch Position	Switch Duration (seconds)	Comments
2-14	WUT	CR	21,000	365	0.80	4.9	418	DISABLE	See Note 1	
2-15	WUT	CR	16,000	360	0.72	4.0	417	DISABLE	See Note 1	
2-16	WUT	CR	15,200	397	0.78	5.0	505	DISABLE	See Note 1	Combined with maneuver 2-17
2-17	WUT	CR	14,700	387	0.75	6.2	477	DISABLE	See Note 1	
2-18	WUT	CR	14,500	402	0.78	6.6	520	DISABLE	See Note 1	
2-19	WUT	CR	10,600	392	0.70	6.9	488	DISABLE	See Note 1	
2-19	WUT	CR	10,000	400	0.71	7.8	514	DISABLE	See Note 1	Over G to 7.8
FLIGHT 1609										Only have TM data/ onboard tape broken
UNDAMPED DYNAMICS										
2-20	WUT	CR	10,800	420	0.76	6.0	571	DISABLE	See Note 1	
2-21	WUT	CR	10,800	431	0.78	2.8	602	DISABLE	See Note 1	
2-22	WUT	CR	NOT COMPLETED					DISABLE	See Note 1	Attempted point twice and got gear door light at ~10K/ 430 KIAS
DAMPED DYNAMICS										
3-1	WUT	CR	31,200	230	0.66	2.4	182	NORMAL	N/A	
3-2	WUT	CR	25,800	252	0.60	3.0	191	NORMAL	N/A	
3-3	WUT	CR	21,300	275	0.60	3.1	232	NORMAL	N/A	
3-4	WUT	CR	16,500	316	0.64	3.0	323	NORMAL	N/A	Combined with 3-5
3-5						3.7				
3-6	WUT	CR	11,900	325	0.60	3.0	341	NORMAL	N/A	Combined with 3-7
3-7						4.0				
3-8	WUT	CR	11,600	322	0.60	4.5	345	NORMAL	N/A	
3-8	WUT	CR	11,000	335	0.60	5.2	353	NORMAL	N/A	REPEAT
3-9	WUT	CR	21,150	335	0.74	3.2	356	NORMAL	N/A	Combined with 3-10

Note 1: During these test points, the cockpit switch was moved from the "NORMAL" position to the "DISABLE" position below gear speed. The aircraft then accelerated to the test condition. After the completion of each test point, the aircraft was slowed down and the switch was returned to the "NORMAL" position to reset the gear.

Table 4 Continued

Test Point	Test Point Description	Aircraft Config	Altitude (ft MSL)	Airspeed (KIAS)	Mach	Nz (g's)	Q (psf)	Cockpit Switch Position	Switch Duration (seconds)	Comments
3-10	WUT	CR	20,700	316	0.70	3.8	324	NORMAL	N/A	
3-11	WUT	CR	21,100	340	0.75	4.7	366	NORMAL	N/A	
3-11	WUT	CR	19,400	356	0.76	5.3	404	NORMAL	N/A	REPEAT
3-13	WUT	CR	15,780	370	0.74	4.0	444	NORMAL	N/A	
3-14	WUT	CR	16,172	377	0.76	5.0	461	NORMAL	N/A	Combined with 3-15
3-15	WUT	CR	15,900	370	0.73	6.0	430	NORMAL	N/A	
3-16	WUT	CR	16,400	390	0.78	6.0	481	NORMAL	N/A	
Worked on gear door arrangement										
FLIGHT 1610										
UNDAMPED DYNAMICS										
2-22	WUT	CR	9,500	453	0.80	6.0	666	DISABLE	See Note 1	
DAMPED DYNAMICS										
3-16	WUT	CR	14,000	410	0.78	6.5	530	NORMAL	N/A	
3-17	WUT	CR	10,200	390	0.70	6.5	496	NORMAL	N/A	
3-18	WUT	CR	10,200	416	0.75	6.5	569	NORMAL	N/A	
3-19	WUT	CR	10,700	430	0.78	6.0	604	NORMAL	N/A	
3-20a	WUT	CR	10,500	438	0.79	6.5	624	NORMAL	N/A	
2-23	Dive (Undamped)	CR	31,300-14,200	218-468	0.94	3.4		DISABLE	See Note 1	(1) 30,000 ft / 0.9 M Initiation of dive. (2) Point Represents the FCF profile dive.
3-21	Dive	CR	33,600-13,700	218-468	0.90	3.7		NORMAL	N/A	(1) 30,000 ft/ 0.9M Dive Initiation (2) Point represents the FCF profile dive.

Note 1: During these test points, the cockpit switch was moved from the "NORMAL" position to the "DISABLE" position below gear speed. The aircraft then accelerated to the test condition. After the completion of each test point, the aircraft was slowed down and the switch was returned to the "NORMAL" position to reset the gear.

Table 4 Continued

Test Point	Test Point Description	Aircraft Config	Altitude (ft MSL)	Airspeed (KIAS)	Mach	Nz (g's)	Q (psf)	Cockpit Switch Position	Switch Duration (seconds)	Comments
FLIGHT 1611										
HYDRAULIC SPIKE										
4-1	Normal Gear Extension	CR to PA	4,980	180	N/A	1	N/A	NORMAL		
4-2	WOW proximity Switch Failure	CR	5,030	182	N/A	1	N/A	DISABLE	Instant	
4-3	WOW proximity Switch Failure	CR	5,050	183	N/A	1	N/A	DISABLE	0.5	
4-4	WOW proximity Switch Failure	CR	5,040	187	N/A	1	N/A	DISABLE	1	
4-5	WOW proximity Switch Failure	CR	5,040	182	N/A	1	N/A	DISABLE	2	
4-6	Intermittent WOW Proximity Switch	CR	4,980	182	N/A	1	N/A	Toggled DISABLE	2	Rapid Toggling
4-6	Intermittent WOW Proximity Switch	CR	5,040	186	N/A	1	N/A	Toggled DISABLE	2	Rapid Toggling
4-6	Intermittent WOW Proximity Switch	CR	4,940	190	N/A	1	N/A	Toggled DISABLE	2	Rapid Toggling
FLIGHT 1620						**Replaced left uplock with old components**				
UNDAMPED DYNAMICS										
2-1	Push Over	CR	10,400	186	0.50	0.45	136	DISABLE		
2-3	WUT	CR	31,500	215	0.65	2.0	159	DISABLE	See Note 1	2g is the limit of the aircraft.

Note 1: During these test points, the cockpit switch was moved from the “NORMAL” position to the “DISABLE” position below gear speed. The aircraft then accelerated to the test condition. After the completion of each test point, the aircraft was slowed down and the switch was returned to the “NORMAL” position to reset the gear.

Table 4 Continued

Test Point	Test Point Description	Aircraft Config	Altitude (ft MSL)	Airspeed (KIAS)	Mach	Nz (g's)	Q (psf)	Cockpit Switch Position	Switch Duration (seconds)	Comments
2-4	WUT	CR	26,150	250	0.62	2.5	198	DISABLE	See Note 1	2.5g is the limit of the aircraft
2-5	WUT	CR	21,100	276	0.61	3.0	245	DISABLE	See Note 1	
2-6	WUT	CR	15,600	285	0.58	3.5	301	DISABLE	See Note 1	Completed 2-6 and 2-7 as one maneuver
2-7						3.6				
2-8	WUT	CR	11,000	330	0.60	3.0	367	DISABLE	See Note 1	Completed 2-8, 2-9 and 2-10 as one maneuver
2-9						4.0				
2-10						4.5				
2-11	WUT	CR	20,250	330	0.71	3.2	334	DISABLE	See Note 1	Completed 2-11 and 2-12 as one maneuver
2-12						4.25				
2-13/14	WUT	CR	21,000	360	0.78	4.9	436	DISABLE	See Note 1	Experienced Pitch Buck, Completed 2-13 and 2-14 as one maneuver
2-15	WUT	CR	16,200	360	0.74	4.2	410	DISABLE	See Note 1	
2-16	WUT	CR	16,100	400	0.79	5.0	536	DISABLE	See Note 1	Completed 2-16 and 2-17 as one maneuver
2-17						6.2				
2-19	WUT	CR	11,900	400	0.72	6.5	500	DISABLE	See Note 1	
2-20	WUT	CR	11,200	425	0.72	6.2	574	DISABLE	See Note 1	

Note 1: During these test points, the cockpit switch was moved from the "NORMAL" position to the "DISABLE" position below gear speed. The aircraft then accelerated to the test condition. After the completion of each test point, the aircraft was slowed down and the switch was returned to the "NORMAL" position to reset the gear.

APPENDIX D: ENGINEERING LOG FOR T-45 UPLOCK INSTALLATION INVESTIGATION

17 September 2001:

COMPLETED THE FORCE CHECK ON THE OLD UPLOCKS (LOWER TIP):
L Gear Up: 5.5 lbs
L Gear Down: 6.25 lbs
R Gear Up: 5.0 lbs
R Gear Down: 7.5 lbs

Installed reworked uplocks:
Please note that neither the right or left uplock came with the 6 mm bolts installed
The uplocks were held together with plastic ties

Measured values with new uplocks installed (lower tip):
L Gear Down: 7.5 lbs (One of the springs was somewhat distorted)
R Gear down: 10 lbs

18 September 2001:

Removed the right uplock to see if the uplock latch would move under its own weight: IT DID NOT

Loosened the 6 mm bolt and the latch moved under its own weight

Re-tightened the bolt to hand tightness and the latch did not move under its own weight

Also verified that the bushing was brown in color vice the reddish color one on the old uplock

Completed a spring check on all of the 8 springs that we had here at Pax:
(Displaced one inch and measured the force using force gauge and measured displacement)
1- 6.25 lbs
4- 6.50 lbs
2- 6.75 lbs
1- 7.00 lbs
- The one spring that was somewhat distorted measured 6.75 lbs when an attempt was made to correct the spring, the force lessened by 1/8 lbs
- Replaced the springs on the left uplock with two springs that measured 6.5 lbs and the total friction force measured was 7.25 lbs (**WE NEED TO ORDER NEW SPRINGS**)

Took apart the re-worked R uplock and there were 3 shims that measured .012 in. Removed and replaced with 2 shims that measure .014in. and torqued to 40-60 in-lbs and now the latch moves under its own weight. Measured .002in. freeplay with feeler gauge. Were asked to remove the left uplock to verify how many shims were installed

There were 3 shims that measured .011in. and a new brownish color bushing were installed
The left uplock was rebuilt and the freeplay checked, there was **NO** freeplay measured with feeler gauge.

19 Sept 01:
Installed an additional shim to create a .0135in. with .002in. lateral freeplay in the system measured with a feeler gauge

Reinstalled the right and left re-worked uplocks

Replaced Springs with new springs

Take friction measurements : Gear Down (lower tip): 7.25 lbs on both sides

20 Sept 01:
Waiting on Springs
Completed Installation of Photogrammetric targets

21 Sept 01:
Prepared for gear swings with instrumentation
Re-checked friction inspection documentation, realized that the measurements were taken at the wrong tip location, re-took friction measurements: Gear Down (upper tip): 10 lbs R, 11 lbs L

Confirmed that when the springs were removed that the latch fell under its own weight

Confirmed that the uplocks were not hard to install and that the external shims were used

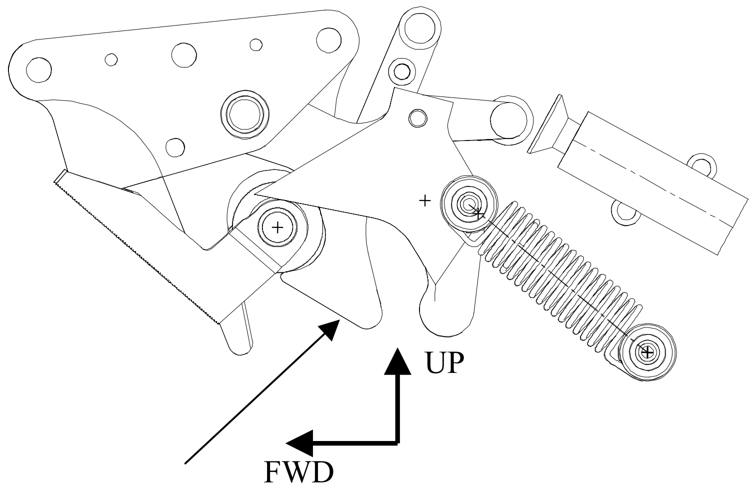
24 Sept 01:
Checked spring force of the 4 new springs (using force gauge and measured distance)
1- 6.25 lbs
2- 6.25 lbs
3- 6.25 lbs
4- 6.50 lbs

25 Sept 01:
Checked what spring gauge we used: 25 lbs Chatilion Gauge certified Aug 21 2001, does not need to be certified again until Aug 20 2003.

Verified that the measurement was taken horizontal to the installation bolt line
Gear Down: L: 11 R: 10.25

The springs were uninstalled, we verified that both of the target links moved freely

Also checked to see the force required to move just the hook and target link with the force gauge applied flat to the lower tip surface as shown below: 1 lb initial breakout force on both sides



Reinstalled the springs
L: 6.25 lbs and 6.50 lbs spring
R: 6.25 lbs and 6.25 lbs spring

Changed the tip of the force gauge to a V-tip so that we could use the tip to use the tip to guide along the tip of the latch. (Used 6-inch extension). When measured forces, the gauge was up against the emergency door release cable.

The L Force was 9.0 lbs (measured 3 times using upper tip)
The R Force was 10.0 lbs (measured 3 times using upper tip)

Measured the displacement of the springs installed in the aircraft (0.5 inch) then measured the force to displace that distance. (We measured 4 springs at 0.5 inch displacement and measured 4.5 lbs- 3 times and 4.25 lbs once)

Verified that the uplock actuator was retracted on both sides of the mechanism

Verified that the emergency landing gear handle was completely stowed

Measured force to move the latch from A053 with the springs disconnected: 2.25 lbs
Measured the force to move the hooks with the springs attached: 8.25 lbs

26 Sept 01: (Ambient Temperature About 75°F)
(Rick Rogers from DEPOT for onsite support):

Re-took measurements:
L/ Gear Down/ Upper Tip: (Bob) 9/9.25/9.25 (Rick): 9.25/ 9.00
R/ Gear Down/ Upper Tip: (Bob and Rick) > 10 lbs

Removed Left Uplock from Aircraft and re-measured components:
External Shim: .02in.
Internal Shim ~.016in.
- There was some minor wear on the Teflon bushing faces: (Can see the evidence of hook rotation)
-Able to rock the prox switch target when applying forces at tip. Less than .002 play at pivot point
-Upper Pin measured per AFC266
Spring Free Measures : (1) 3.165 (2) 3.160
Rebuilt the uplock using the same shims
Freely falls

Installed Re-worked Left uplock in model fixture for A053 uplock
Measured the force in the fixture: (Bob) 8.2 lbs (Rick): 7.5 lbs
Took force measurements with one spring connected: 4 lbs with either spring

Tried to measure the shim without tearing apart component: Estimated .018in.

27 Sept 01: (Ambient Temperature at Start about 50°F)
Reinstalled old A053 uplock into model fixture and took measurements:
7.5 lbs/ 7.75 lbs/ 7.75 (Horizontal) (Note: this is .5-.75 lbs less than measured Tuesday)
Changed to along load line (30°) and measured 6.5/ 6.5/ 6.25 lbs
Unable to get a .0015in. feeler gauge in component

Reinstalled new left uplock back into model: Measured 7.75/ 7.75/ 7.75 lbs

Recompleted spring measurements on the two springs from A037 Left uplock and A053 right uplock at 0.5in. and 1in. increments the spring measurements were:
New: 4.25/ 6.5 lbs(0.5in./ 1in.)
New: 4.35/ 6.5 lbs
Old: 4.25/ 6.5 lbs
Old: 4.0/ 6.0 lbs

Re-checked shims from L uplock = .005in.
Removed the .002in. shim from A037 L Uplock, reshimmed to .013in. rechecked with feeler gauge .002in. freeplay.

-Can notice some wobble in the assembly when the hook point is moved laterally (Appears to wobble in the bushings)

Measure hook point pin diameter and corresponding bushing ID's
Side Plate: 0.472in.
Guide Plate: 0.472in.
Side Plate Hook Pin: 0.470in.
Guide Plate Hook Pin: 0.470in.

Reassembled L A037 uplock and reinstalled in Aircraft
It is a contact fit, but was done by hand
Upper Pin measures .39in. in diameter
Spacer diameter measures: 0.375in./ 0.380in.

Re-Checked forces:
L /Gear Down/ Upper Tip: 8.25/8.75/ 8.75 lbs
R/ Gear Down/ Upper Pin: 8.75/ 8.75 lbs

Measured Simulated Gear Up (Having problem with tool installation technique)
L ~ 6 lbs
R~ 6.75-7.25 lbs

Installed a heat lamp on L Uplock to see if temp would change values:
Baseline: 71°F 8.25/ 8.75/ 8.75 lbs
At 122° F there was no noticeable change in the force or freeplay (measured installed in a/c)

R Uplock Gear Down 8.75/ 8.75 lbs
Freeplay: 0.003in.
Gear Up: 6.75/ 7.25 lbs
Removed R A037 uplock from aircraft

Disassembled Values:
.015in. Internal Shim
.030in. External Shim
Guide Plate Bushing: 0.472in.
Side Plate Bushing: 0.472in.
Hook Pins (Both): 0.470in.
Spring Checks:
4.0/ 6.0 lbs (0.5in./ 1.0in.)
4.5/ 6.5 lbs
Installed A053 Uplock into aircraft:
Gear Down Check: 9.0 lbs

Sim Gear Up Check: 7.0 lbs
Free Play: < .0015in.
Target Link rubbing hard on the uplock beam outboard edge: Has large diameter pins and spacers installed

Measured Diameters of Gear Up Tool: Small Diameter Section Measured : 0.745in. should measure 0.78/0.80 lbs
Added tape to increase diameter to 0.775in.
Reinstalled tool into uplock assembly and applied slight load on tool and measurements on A053 R uplock were < 5lbs

L Gear Up (as measured on A053): 5.75/ 6/ 5.25/ 5.0 lbs (Horizontal)
L Gear Down: 7.5/ 8.25/ 8.0/ 8.0 lbs (Horizontal)

Reinstalled Re-worked R uplock
Gear Down: 8.75/ 8.5/ 8.5 lbs (Taken Horizontal)
Gear Down: 9.0/ 9.0 lbs (Aligned ~30° along load line)
Gear Up: 7.5/ 6.0/ 6.0/ 6.0 lbs (Horizontal)

Disassembled A053 uplock:
1 shim = 0.02in.
Bushing de-laminated from sideplate
Disassembled target link assembly:
    Teflon Face Bearing
    Need to check print for pin installation

1 Oct 01:
Took R uplock apart and took target link off
- Noticed corrosion on the shim (split into two pieces)
- Possible corrosion on the bearing assembly

Ordered replacement shim and rivets to put component back together

3 Oct 01:
Rebuilt R uplock and reinstall into the aircraft

Prepare for gear swings and video swings

Installation R uplock Gear Down: 7/9/7.25 lbs
Gear Up: 7/7/7 lbs

Completed Gear Swings (4 Oct 01)

VITA

Christina Marie Stack was born in Baltimore, Maryland on August 15, 1974. She graduated from Severna Park High School in May 1992 and started at the University of Maryland College Park in August of 1992. In August 1993 she transferred to The Pennsylvania State University, where she received her Bachelor of Science Degree in Aerospace Engineering in May 1996. In May of 1996 she started her career with the Naval Air Systems Team at the Naval Air Weapons Center Aircraft Division (NAWCAD) Patuxent River, MD. After a 10 month rotation at the uninstalled engine test cells at the Naval Air Propulsion Center, Trenton, NJ she started her career in the flight test group at NAWCAD Patuxent River, MD in the installed propulsion and air vehicle subsystems branch. From 1997-1999 she participated in the Engineering Manufacturing Developmental (EMD) test of the F/A 18 E/F program. At the completion of EMD she became a student at the Naval Test Pilot School (TPS) in January 2000. Upon graduation from TPS in December 2000, she started as the propulsion engineer on the X-31 program. The X-31 flight test program flew on and off from March 2001 until April 2003. During the off periods for the X-31 program, she worked on projects on the T-45. At the completion of the X-31 program, she became the team lead of the 5 engineers from the installed propulsion and air vehicle subsystems, which support the T-45 program. She currently lives in Patuxent River, MD.